Working Document
No 148

Annual Report 1994

TROPICAL LOWLANDS PROGRAM

April 1995

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EXECUTIVE SUMMARY

Strategies

The research activities of the TLP fall broadly in two major categories (a) within agroecosystem *area based research* activities leading to the identification development and testing of prototype sustainable land use systems for representative sites in the savannas and forest margins based on an understanding of the underlying biophysical and socioeconomic processes and mechanisms and (b) *across agroecosystem research* led by or in cooperation with the Land Use SRG aimed at providing policy options and defining the profile of potential technological innovations and based on an understanding of past and present trends in land use and the analysis of past and present policies Area based research in the forest margins begun in the first semester of 1994 while that of the savannas was formally initiated in 1992 Exploratory research across agroecosystems traces back to the studies leading to the development of CIAT s Strategic Plan

The above set of research activities are organized around three major types of projects (1) dynamics of land use (2) mechanistic understanding of soil chemical physical and biological processes in agropastoral and sequential crop systems (3) development of prototype cropping systems plus a smaller set of special funded more specific projects To various degrees all of these attempt to quantify the tradeoffs involved in interventions in the two tropical lowlands agroecosystems researched namely the neotropical savannas and the intervened rainforest margins Functional aspects of the two agroecosystems are (1) the *provision of resources for agricultural production* both primary and secondary (e g soil water plants etc) (2) the provision of various *environmental services* including amenities and life support mechanisms (e g ecosystem stabilization climate regulation maintenance of genetic diversity) and (3) *assimilation of waste products* (e g CO_2) Within this very large array of researchable issues CIAT places particular but not exclusive emphasis in the use and maintenance of the soil resources in view of the prevalence in both agroecosystems of marginal and low fertility soils and to the impact of farmers decisions regarding land use on natural resources In concurrence with CIAT s strategy in resource management the Program positions itself as one participant in the large array of R&D institutions involved in RMR in these agroecosystems Based on its international nature and neutrality the Program attempts to play a facilitating role in promoting the involvement of other research institutes in both agroecosystems

The highlights outlined in this report intend to document how the Program is attempting to carry out this dual role involving its own research most frequently developed in cooperation with others and research by other institutions which have been prompted by our own activities In this context special mention needs to be made of some institutions whose collaboration is essential for the Program s activities In our host country the support and collaboration received from CORPOICA Carimagua is crucial to the success of the Llanos work and the same comment applies to the contributions of EMBRAPA CPAC in the Brazilian Cerrados and CPAF Acre and CPAF Rondonia in the Forest Margins area Notwithstanding numerous other collaborators two international institutes have significantly contributed to the Program s research activities These are IFDC USA who has assigned a Soil scientist to work with the TLP in the area of soil fertility management and CIRAD France which has assigned a Savanna ecologist to conduct research on plant dynamics in the Colombian Llanos Major Program donors were the Colombian Government and the Inter American Development Bank

Research activities

<u>Understanding land use dynamics</u>

Understanding and predicting development paths of both agroecosystems and their interactions implies the analysis of past trends in land use the analysis of past and current *policies and modelling* of future alternative scenarios conditioned by potential policies and technologies

Such an analysis began in 1994 based on literature review and secondary data The root causes of deforestation in the Amazon are the opportunities it provides for land speculation to the rich and for increased labor returns to the poor The driving forces behind these opportunities originate primarily in government policies both within and outside the agricultural sector In the savanna productive technologies have enabled areas with good infrastructure to make important contributions to national agricultural production at the expense of on and off site degradation Speculative land demand has expanded the agricultural frontier into marginal areas A modelling exercise to depict future land use scenarios up to the year 2020 and their implications in terms of productivity labor absorption and ecological sustainability was initiated jointly by the TLP the Land Use SRG the Impact Assessment unit and an NGO Preliminary results show that the combination of favorable policies and technologies for ecosystem management could make a major contribution towards simultaneously reducing deforestation while *enabling national governments to obtain economic* and social benefits from the forest margin Significant increases in agricultural output and agribusiness could be sustainably achieved in the savanna and this could enable it to divert pressure from the Amazon by contributing to government s economic objectives diverting venture capital and absorbing labor in agribusiness Aspects of the favorable scenarios have started to occur in recent years Among them are changes in policies emerging international markets in ecological services which could provide powerful incentives for the adoption of *sustainable systems and* new ecological paradigms which provide opportunities for combining environmental enhancement with economic gain This constellation of events provides a unique opportunity for effective ecosystem management

Assessment of possible future land use scenarios require continued understanding of the factors driving farmer s adoption of new and emerging technologies An adoption study of pasture based technologies in the Colombian savanna showed that 98% of sample farmers had planted improved pastures 17% of the surveyed area consisted of planted pastures with the area increasing in the last 15 years at the rate of 14% p a Only 18% of the improved area contained legumes and 1 5% was planted to the rice pasture technology the latter being a new technology at the time of the survey The predominant strategy of farmers was to supplement native savanna with a small area of planted grass pasture which was increased over time as capital became available Capital and management requirements were identified as key factors inhibiting area expansion of planted grass pastures and adoption of grass legume pastures and ley farming systems As natural increase in herd size occurs farmers appear to be accepting *improved grass pastures as an alternative* to over grazing The study shows that reduction of the capital and management intensiveness of ley farming systems even at the expense of productivity could make a major contribution to the prevention of over grazing by speeding up the rate of adoption In terms of the savanna as a whole the study area lies towards the unfavorable extreme in terms of soil fertility In terms of infrastructure it is moving rapidly from the typical towards a more favorable direction The ley farming technology in its current form should be targeted to the most favorable areas of the savanna

Another external factor that may condition future land use in the forest margins and at least parts of the savannas is the emerging development of international markets for ecological services Technological interventions such as deep rooted germplasm that can effectively sequester C in depth and possibly affect the exchange of other gasses as well (see below) may have an important role in the future and constitutes an area which the Program will modestly explore to assess implications for further technological developments

A great deal of effort and very significant resources were deployed in 1994 for the continued characterization and in depth analyses of land use dynamics in the two target agroecosystems under the leadership of the Land Use SRG Given resource limitations the Acre Rondonia area was prioritized followed by the Colombian Llanos Some efforts were made to obtain additional and more detailed secondary information to improve the characterization of selected sites in the Cerrados of Brazil while characterization of the Venezuelan Savannas in cooperation with a number of national institutions has been on hold

System characterization research has been conducted in Acre and Rondonia in the Brazilian Amazon as part of the global initiative Alternatives to Slash and Burn Agriculture (ASB) funded by GEF and coordinated globally by ICRAF and by CIAT in Latin America and in partnership with EMBRAPA (in Acre and in Rondonia) PESACRE ICRAF IFPRI CIFOR and TSBF The purpose of the ASB is to develop technical and policy alternatives which would help to decrease rates of tropical deforestation while enhancing the well being of forest resource users

Tropical deforestation a contributor to global warming via release of atmospheric CO_2 is highest in Latin America compared to Africa and Asia Rates in the Amazon Basin of Brazil increased from the early 1960s through the mid 1980s due to national policies supporting road building tax and credit incentives to large corporations and ranches and colonization projects for the rural poor Changes in the same policies seem to have contributed to observed declining rates of deforestation for the Brazilian Amazon as a whole

Interviews conducted in the project area indicated that settler colonists had parcels of a mean 88 ha in Pedro Peixoto (Acre) and 76 ha in Theobroma (Rondonia) These lands were approximately 60% in forest and 40% cleared for pastures and crops at the time of the interviews Farmers cleared slightly more than one ha per family per year to produce first rice for which yields were calculated to be approximately 1 5 t/h in the first year but dropped drastically such that maize and cassava were grown in second and in some cases a third year of cultivation Lands were then converted to pasture as farmers not only banked their savings in cattle (some 85% of the settlers had cattle with herd sizes of about 25 30 head) but also and perhaps more importantly sought to take advantage of substantially higher values for improved lands i e cleared lands with pasture fencing corrals and ponds

Development of alternatives to slash and burn agriculture which would decrease rates of deforestation increase sustainability of resource use and enhance the well being of settlers would have to combine on farm and policy research

A detailed GIS coverage is being developed for the study area between Puerto Lopez and Puerto Gaitán Meta in the Colombian Llanos This will help refine existing (Cochrane s et al) classifications monitoring of land use changes and allow extrapolation of technological and policy options Maps of soils and soils characteristics drainage topography vegetation etc have been digitized Critical to the effort of the Program in assessing externalities associated with present and potential land uses is the development of a digital elevation model which will allow accurate estimation of slopes and runoff for applying watershed management and erosion control models This is an ongoing highly time consuming activity Satellite images for previous years were obtained and are being subjected to unsupervised classification we expect to obtain a new satellite image for 1995 which will be ground truthed to allow supervised classification of current land use

To complement the above efforts farms located in contrasting land systems (as classified originally by Cochrane et al) and that differ in the use of savanna resources have been monitored for over 18 months Inputs and outputs for specific fields and/or whole farms are quantified to the extent possible and soil vegetation and other resources are being characterized All of the data has been georeferenced but there are lingering doubts regarding the precision of the GPS instruments used so far The recent acquisition of precise GPS instrumentation by the Land Use SRG will allow verification of the coordinates in 1995 following which the data can be incorporated into a GIS database and overlayed onto the maps and images referred to above for use in land use simulation and other purposes Similarly extensive studies were conducted during 1994 on the floristic composition of native savanna which constitutes the main (>70%) land use form of the region Species diversity was quantified during 1994 for a large cross section of the undulating savannas or *serranias* a formation that constitute nearly 60% of the Colombian and possibly also a large percentage of the Venezuelan savannas As before these data have been georeferenced and extensive soil and plant tissue analyses were conducted Interviews with ranch managers and indigenous communities were also undertaken to assess management practices applied to native savanna communities that may affect plant dynamics On the whole 173 plant species were identified belonging to 40 different families Only 89 of these species are common to the levelled savanna studied in the past in Carimagua and surrounding areas Large differences in plant species composition associated with topography soils and seasonal hydrology exist but additional and longer term research is still required to understand and quantify the contribution of these plant communities to the savanna ecosystem and the possible tradeoffs involved if land use intensification significantly affects some or all of these important communities This is an area that requires the contribution of other disciplines particularly tropical ecology and for which the Program is attempting to involve other research institutions

As indicated previously longer term studies of the dynamics of savanna vegetation in response to current and potential uses are required A large ongoing experiment set up in Carimagua was designed to provide information on the effect of season and frequency of burning and of grazing management on vegetation dynamics above ground and underground biomass production and seasonal changes in grazing preference Large differences are apparent in terms of species dynamics but it is still too early to draw conclusions Complementary observations are made on some of the farms being monitored as explained above Plant dynamics and changes in soil parameters are evaluated and will be related to management practices employed by farmers

Process oriented biophysical research

Intensification of land use in the savannas may bring about changes in many of its land resources including above and under ground fauna and in limnological properties of savanna water streams The latter two are not areas in which the Program has expertise An exploratory survey of above ground fauna is being conducted at Carimagua by a professor of the National University of Colombia Department of Biology Bogotá made possible by the financial support provided by CORPOICA Carimagua and the TLP An initial survey of soil fauna conducted earlier on by a French student in the Colombian Llanos led to the design of a much more ambitious ongoing project conducted by a Spanish student under the supervision of an ORSTOM (France) specialist and a professor of the Universidad Complutense de Madrid The study takes advantage of a large longterm experiment setup in Carimagua involving a wide range of highly contrasting prototype cropping and pasture systems that allows quantification of changes in soil fauna in response to temporal changes in land use Given the low natural fertility of savanna oxisols the experiment investigates a combination of crop and/or pasture components at two levels of intensification based on lime to determine biophysical measures of system performance and health This as well as an equivalent experiment set up in the Cerrados of Brazil are jointly run with the respective national institutions CORPOICA and EMBRAPA CPAC respectively plus the Universities of Bayreuth (Germany) and Cornell (USA) in the Brazilian case A large team of researchers is involved in both cases The Carimagua *culticore* experiment was set up partly in 1993 and the rest in 1994 The experiment essentially contrasts three major prototypes that modify soil and vegetation to various degrees with grazed native savanna representing the lowest degree of human intervention and a maize based set of treatments representing the highest degree of resource modification This last year witnessed the implementation of the high lime maize based systems using cv Sikuani commercially released by CORPOICA and CIMMYT for the Colombian Llanos in 1994 Legume green manures included as part of the system rapidly showed at least one of the tradeoffs involved In effect grain yields significantly increased following the green manure but so did the concentration of NO_3 N down the soil profile suggesting that N leakage in these soils is a real possibility Maize grain yields in the experiment were 2 5 t ha^{-1} or approximately 1 ton less than in adjacent satellite experiments probably due to a combination of poor establishment and problems of machinery at sowing This is illustrative of some of the problems in setting up long term experiments with contrasting components when their agronomy is still not well developed Nevertheless the experiment is extremely successful overall and provides a common ground for a large interinstitutional and multidisciplinary team that is investigating nutrient cycling processes input/output relationships soil and crop management issues and soil fauna dynamics Results of this experiment are being used to calibrate available crop growth models that will allow the simulation of numerous other crop and pasture sequences and hopefully extrapolation to other soils as well

The Brazilian long term experiment or *crop pasture integration experiment* completed its third cropping year with the best treatments yielding in excess of 7 t ha^{-1} of maize Major yield effects so far are due to soil fertility management which in turn affects the weed population Although soil mechanical impedance has began to deteriorate under continuous cropping and to a lesser extent under a grass legume pasture as compared to the native Cerrado no detrimental effects are apparent as yet On the other hand mycorrhizal populations monitored over the last three years have shown temporal variations in relation to treatment Initially there was a 25 fold increase during the pasture establishment phase and a 3 fold increase in soybeans relative to Cerrado but the differences have decreased significantly over time Detailed studies on soil organic matter contents and distribution and water and nutrient dynamics are being carried out The same experiment is being used by an EMBRAPA Cornell University team to monitor changes in carbon dioxide nitric oxides and methane *Preliminary results suggest that these soils may constitute a large methane sink* with methane oxidation being largest under corn and smallest under native Cerrado Nevertheless pore size and soil water balance as affected by tillage appear to modify some of this ability to dispose of methane

Current trends in tropical soil fertility management stress reliance on biological processes including the use of soil adapted germplasm enhancement of soil biological activity and optimization of nutrient cycling to maximize efficiency of use of external inputs The above listed longterm experiments together with a large array of short term field and laboratory trials are being used to quantify and model nutrient cycling processes Crops residues and crop and forages litter appear to play a key role in savanna oxisols and the lignin N ratio is the main regulator of decomposition with C N ratios and the polyphenols contents playing smaller roles The CENTURY model appears to be reasonably well suited to model some of these N cycling processes if modified to accommodate present experimental results The transfer of N in forage legume litter to the associated grass was very slow whereas urine N was shown to cycle much faster This combination of the effects of organic additions via residues litter *and/or animal manure and urine were shown to improve nutrient conditions* for soil flora and fauna and as consequence appear to beneficially modify organic P availability measured using more elaborate partitioning techniques than the traditional laboratory methods An excellent indicator of these changes in the biological properties of savanna oxisols appears to be soil microbial biomass to the extent that nutrient cycling is very tightly linked to its turnover rate In fact P flux through microbial biomass at least under grass legume pastures (12 34 kg ha^{-1} year^{-1}) indicates that this could be a major pathway of P cycling in these soils These findings are supported by the detection of high phosphatase activity under pastures which further indicates the importance of biological processes in soil P turnover

Introduced grass and grass legume pastures were found to make a major contribution to soil organic matter to a depth of at least 100 cm in both on station and on farm experiments As a minimum it was estimated that a three year old *B dictyoneura* pasture contributes 30 t C ha^{-1} in 3 years and that the addition of a legume significantly increases the amount of C sequestered These findings were published in ***Nature*** and do not require further elaboration here

<u>On farm testing of prototypes</u>

Longterm controlled experiments are absolutely essential to develop a detailed understanding of soil plant animal processes as shown above Nevertheless they have a certain rigidity regarding the crop and/or pasture components that can be tested To compensate for these limitations and more importantly to incorporate into the Program s research agenda farmer s perspectives and preferences regarding resources use a limited amount of on farm work is conducted in all of the area based activities carried out by the TLP This set of trials have the longest tradition in the savannas of both Colombia and Brazil whereas they only begun to be implemented in Acre Rondonia in mid to late 1994 To various degrees and depending on the specific location farmer participation *in the design and conduct of the trials is included* Thus farmer s controls are always included and farmers are involved in the discussion leading to selection of some of the experimental treatments selection of crop or forage components etc whereas still other treatments are purely researcher selected To the extent that farmer decision making processes are documented in these on farm activities this research is considered to be as strategic as that of purely biophysical origin

Only a brief mention is made here of one of these on farm tests whereas the rest are deferred to the main body of the report The *Matazul* on farm trials in the Llanos of Colombia were described in the Savannas Annual Report 1992 1993 The oldest two trials in this farm completed 6 years in 1994 One of them involved continuous rice monocropping using the best available knowledge regarding management of soil physical and chemical properties Over the period 1989 1992 there was a linear decrease of 400 kg ha^{-1} $year^{-1}$ Improved soil management practices applied subsequently were able to partially reverse this trend but continued negative changes in soil compaction weed buildup and decreased microbial biomass continue to conspire against the longterm success of this alternative Studies conducted on weed dynamics their nutrient uptake and overall competition with the sown crop are beginning to identify desirable plant ideotypes that could potentially be undersown to rice and compete with undesirable weeds In general then the monocrop prototype is providing very valuable information on the extent rate and characteristics of degradation processes in savanna oxisols

An equally old experiment whose details have been extensively reported elsewhere the rice pastures experiment entered into the second phase of pastures in the rice pasture rotation in 1994 following a renovation of the original pastures with rice in 1993 This experiment is beginning to illustrate some of the longterm tradeoffs involved with these relatively intensive systems Pastures established under rice support high carrying capacity and higher levels of animal production than otherwise By the same token some aspects of the soil physical properties such as compaction estimated using traditional methods (cone penetrometer) begin to deteriorate relatively early on during the pasture phase A crop phase namely rice temporarily reverses this trend Trends in soil organic matter and microbial biomass contrast markedly with those of the monocrop referred to above

In the Acre Rondonia area (Forest Margins) agronomic work began in the second trimester of 1994 initially severely constrained by logistical and transportation difficulties later overcome Existing agronomic knowledge on potential agrosilvopastoral components is scarce and make it unadvisable to set up longterm complex experiments as yet Following the research agenda agreed upon with the other participants in the Alternatives to Slash and Burn project the Program began its research activities with the introduction of germplasm of the main staple foods in the region namely beans maize rice and cassava to be followed later on by grass and legume forages including multipurpose shrubby and tree legumes Fertilizer inputs although included as experimental treatments are unfeasible under the current economic conditions so that biological management of soil resources is even more crucial than in the other mandated regions of the Program Initial still highly tentative results suggest that it is possible to use dead mulches that protect the soil while at the same time reducing the incidence of web blight in beans based cropping systems A number of mulches was tested both on station and on farm including velvet bean *Pueraria phaseoloides* maize and rice Preliminary results indicate that mulches such as those provided by *P phaseoloides* that decompose at a slower rate provide better protection against web blight and presumably protect the soil for a longer time Nevertheless it was obvious that the majority of the introduced lines and varieties did not have an yield advantage over farmer s checks (mostly Carioca)

Inter program projects

Brief reference was made above to various research activities involving collaboration of Program scientists with other researchers both inside and outside CIAT Several other joint projects will be mentioned here

Several Program scientists were instrumental in designing and implementing a large interprogram project in the Cauca (Colombia) hillsides together with members of most other CIAT s programs A program specialist is also responsible for the maintenance and characterization of the forage legumes Rhizobium collection and for screening and selecting Rhizobium strains in cooperation with the Tropical Forages Program Several Program scientists were heavily involved in designing and implementing maize based cropping systems with CIMMYT and CORPOICA in the Colombian Llanos Similarly Program researchers actively contributed to evaluation of maize rice and forages germplasm for alternative production systems in the Cerrados of Brazil and maize rice cassava beans and forages germplasm in the Acre Rondonia sites

Institutional strengthening and relations

In the area of institutional building several important events took place during 1994

A C sequestration workshop took place with the participation of several NARs and international institutions to develop an interinstitutional project on the subject for submission to potential donors

Similarly the Program was heavily involved in a Land Use led workshop leading to development of a regional project for the savannas entitled *Strategies for Sustainable Agricultural Land Use in the Lowland Savannas of South America* SSALLSSA

The Program participated in the Global Steering Committee meeting of the ASB Project and later on in a training workshop on characterization offered in Nairobi Kenya in the context of that same project

The third Workshop on Agropastoral Systems was held in Venezuela which was supported by IDB and Venezuelan funds Junior staff of the TLP were heavily involved in the development of an International Course on Agropastoral Systems for Acid Soils offered in Villavicencio Colombia for extension agents and private technical assistants

Lastly numerous students developed their BS and MS thesis working in existing research projects

In a different context various Program scientists were regularly involved in technical consultation meetings with the MAS consortium PROCITROPICOS and its savannas consortium PROCIANDINOS FAO CORPOICA and various others Similarly through some of its members the Program has been involved in two system wide initiatives namely CIAT s Ecoregional project and the Soil Water and Nutrient Management initiative Lastly it also provided limited input through the Tropical Forages Program to the system wide livestock initiative

CHAPTER I

PROJECT TA 02 DYNAMICS OF LAND USE

(Contribution to Dynamics of Land Use TL01 TA02)

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The purpose of this project is to develop technological options for arresting soil nutrient depletion as well as policy options for promoting stabilization of shifting cultivation 1994 activities focused on diagnosis

The first study reported here gives a broad overview of land use trends in the region and implications for policy and technology development The second study uses primary field data for a detailed investigation of land use dynamics in two government colonization projects in the western Amazon of Brazil GIS work was also carried out in these areas and is reported under project UT51

THE FOREST MARGINS AND SAVANNAS A UNIQUE OPPORTUNITY FOR CONTRIBUTING TO NATURAL RESOURCE MANAGEMENT

The objective of this study is to contribute the socioeconomic component towards developing a strategy for the forest margins (FM) and savannas The work reported here is the first step towards achieving this objective Literature review and secondary data is used to synthesize an understanding of past land use trends and new emerging trends Preliminary results of a land use model which simulates land use changes up to the year 2020 under alternative policy and technology development strategies are presented The results show that the conjunction of a number of national and international developments makes this a highly propitious time for mounting a concerted effort for improving the management of natural resources in the FM and savanna The vision developed on the basis of this broad overview will be progressively refined in the next few years through in depth on farm studies in sites selected through GIS analysis

Savanna vs Hillside countries

The common perception about the three ecosystems in CIAT s ecoregional mandate are quite distinct Agricultural expansion in the FM is internationally regarded as an environmental catastrophe The Hillsides are considered to be locked in a vicious cycle in which poverty reinforces environmental degradation By contrast the savanna is regarded as the last agricultural frontier in the world with a very significant potential to be economically exploited for agricultural and livestock production We therefore broadly distinguish between two groups of countries The savanna countries which have the possibility of developing the savanna as a means of diverting pressure on the FM and Hillsides and the Hillside countries which do not have a savanna ecosystem Macro data show that the savanna countries have lower population growth rates higher per capita incomes and higher rates of economic growth including agricultural output The incidence of poverty and food imports are also lower in savanna countries However populations are larger and the absolute numbers of poor are higher Because of these differences land use strategies are likely to differ among the two groups of countries The work reported here focuses mainly on the savanna countries Brazil Colombia and Venezuela which contain over 90% of the total savanna area

Land use dynamics

Historically the FM was occupied by indigenous shifting cultivators although boom and bust periods for extractive industries have occurred sporadically during the last century Extensive cattle grazing has been the traditional activity in the savanna since the colonial period The exceptions were the center south of the Brazilian savanna (C S) which was stimulated by infrastructure and the construction of Brasilia in the 1950s into becoming an important commercial center for cattle production and processing and the western savanna in Venezuela where agricultural production was stimulated by incentives financed by oil revenues Rapid frontier expansion occurred in both the savanna and FM from the 1970s In the Brazilian savanna (cerrado) the frontier expanded on an average by 2 1 m ha per annum between 1970 and 1985 with 70% of the cerrado incorporated into farms by 1985 In the Brazilian Amazon the rate of deforestation was 1 5 m to 2 m ha /year However there is still considerable opportunity for influencing the future pattern of land use as only 6% of the Brazilian Amazon has been cleared What is less well known is that the risk of species extinction is higher in the forests of the cerrado than in the Amazon as a third of the cerrado forests have already been cleared in many cases for charcoal production Pasture is the dominant form of land use in both ecosystems occupying 60% to 82% of the cleared area in the cerrado and 60% to 70% in the Brazilian FM In the cerrado the importance of pasture *increases as agricultural development advances (Table 1 and 2)* Concentration in land ownership is characteristic of both the savannas and FM In the cerrado 87% of the land is in farms ranging from 200 to >10000 ha What is less well known is that there are substantial numbers of relatively small farms More than 50% of farms are less than 50 ha in size These small farms are mainly located lower down the topography often along the river beds They play a critical role from the environmental point of view both because the river beds are where the gallery forests are located and also because of the potential impact of their farming practices on siltation and pollution of rivers Over time land concentration has remained virtually stable though there has been a small decline in the proportion of farms less than 50 ha and fragmentation of farms larger than 10000 ha In the FM land concentration is lower than in the cerrado but still high with a Gini coefficient of 0 79 in 1985 Small and large farms coexist but there is a high degree of social conflict particularly between large scale absentee landlords and small scale squatters Shifting cultivation by small holders is estimated to account for 32% of tropical American deforestation taking place in 1980

There have been major population movements into the FM particularly in the 1970s and substantial labor absorption in agriculture Movement of population into the savanna has been much less(Table 3) In advanced agricultural areas substantial declines in rural population have occurred simultaneously with rapid urban population growth In the municipality of Uberlândia in the C S of the cerrado rural population in 1980 was 47% of the population in 1950 However urban population which comprised 96% of the total population in 1980 was more than 6 times the 1950 level Presumably urban population increase occurred because with improved infrastructure Uberlândia had developed into a major center for agribusiness Whether or not the migrants into the urban areas came from rural areas of the savanna is however not known The diversity of conditions within the savanna needs to be emphasized Within the cerrado for example the advanced agricultural area (C S) while occupying a third of the area contains 60% of the population supplies 83% of the cerrado s soybean production and contains about a third of its cattle In the more remote areas extensive cattle ranching is the norm (Table 1) Within the FM a broad distinction is required at minimum between areas such as Para (Eastern Brazil) where the government provided incentives for large scale ranching and areas such as Acre and Rondônia (Western Brazil) where government sponsored small scale settlement took place Small and large scale farmers coexist in both areas but the dynamics of land use have been different as will be shown later In Colombia where most settlement was spontaneous the situation is closer to areas of small scale settlement in Brazil Technology development in the past has sought to increase land productivity through the replacement of natural vegetation and traditional species with new varieties chemical inputs mechanization and irrigation of dry areas A high level of technology adoption has occurred in limited areas of the savanna where high land values good infrastructure and proximity to markets made technologies of this nature worthwhile In these areas agriculture is regarded as highly successful The cerrado for example provides 25% of Brazil s soybean output and contains a third of the cattle population The recent free trade pacts being negotiated between Latin American countries should stimulate development in these areas as economic analysis shows that the savanna has a comparative advantage in livestock and in soybean up to a distance of 2000 km from ports In the more remote areas of the savanna technology adoption has been very limited and extensive cattle ranching is the norm Little attention has also been given to the development of technologies appropriate for small scale savanna farmers whose crops and resource endowments tend to be very different from those of large scale farmers

Table 1 Land use in the Brazilian savanna (Cerrado)[1]

	Cerrado		**Modern Sub region (C S)[2]**		**Rest of cerrado**	
Total area (m ha)	**155**		**50**		**105**	
	1970	**1985**	**1970**	**1985**	**1970**	**1985**
Area within farm boundaries (% of total)	53	70	70	85	45	63
Cleared area within farms (% farm area)	23	47	28	61	20	37
			% cleared area			
Crops (including planted forest)	16	19	20	19	12	19
Planted pastures	45	61	69	75	31	46
Cleared but unused	39	20	20	6	57	35

[1] Source Mueller et al 1992

[2] Center South of Cerrado area around Uberlândia/Goiânia See Mueller et al 1992

Table 2 Land use in the forest margins of Brazil

	Pará/Tocantins[1]	Acre/Rondonia[1]	Altamira[2]	
	1985	1985	1985	1991
	%			
Agriculture (annual/perennial)	7	29	4	7
Pasture	73	57	2	9
Secondary growth				
4 6 years	n/a	n/a	12	13
6 10 years	n/a	n/a	9	20
> 10 years	n/a	n/a	2	6
Total	20	14	23	39
Forest	n/a	n/a	57	55

[1] Source Mueller et al 1992 % incorporated land
[2] Source Moran et al 1994

4 6 years bush fallow
6 10 years Woody species
> 10 years close to mature forest

n/a = not available

In the FM adoption of improved pastures has occurred but extensive management practices remain the norm in large scale ranches Among small holders annual crops are grown with minimal external inputs In Brazil yields of rice maize and cassava have decreased sharply over the 1984 to 1990 period in the FM in contrast to significant yield increases at the national level The environmental effects of land use systems include fragmentation and reduction of natural habitats loss of ecosystems and species changes in hydrological cycles soil and water pollution compaction and soil erosion associated with the intensification of agriculture and significant emissions of green house gases due to deforestation Brazil is now the fourth largest contributor to atmospheric carbon in the world

Table 3 Employment and demographic change in the forest margins and savanna of Brazil[1]

	Forest Margin		Cerrado	
	Pará/Tocantins	Acre/Rondônia	C S	Cerrado (Total)
Population growth rate (%)				
1970 1980	8 4	11 4	3 4	2 7
1980 1991	4 9	6 3	2 5	2
Workers/100 ha of agricultural land				
1970	85	85	7	6
1985	67	70	4	3

[1] Source Mueller et al 1992

Explaining land use patterns

The root cause of frontier expansion has been identified as the Latin American style of development A large section of the population has been excluded from the benefits of growth and development Also macroeconomic conditions have resulted in inadequate and uncertain returns to financial assets (Table 4) Thus the frontier has been an escape valve for the discontent of the poor and the capital of the rich Inequality has its roots in the high levels of mechanization in both agriculture and industry which limited employment opportunities and led to large scale rural outmigration from advanced agricultural areas The causes of this were historically high levels of land concentration government policies such as negative real interest rates and subsidies for mechanization and urban bias in social amenities which led to high rates of urbanization In addition population pressure in the hillsides of the Andean countries and Northeast Brazil led to rural outmigration which was reinforced by government small scale settlement programs in partes of the Brazilian FM In Colombia people sought to flee from the political violence of the 1950s and 1960s These push factors caused the poor to look to the frontier as an escape valve (Figure 1)

The capital of the rich was drawn to the frontier because frontier land prices contained a speculative component which pushed prices well beyond actual production values Factors contributing to this were the construction of penetration roads government policies linking land titling to productive land use access by landowners to credit at strongly negative real interest rates (25% to 35% between 1979 and 1986 in Brazil) and opportunities for illicit cultivation and processing of coca (in Colombia) In addition to this negative real interest rates high unstable inflation (over 80% in Brazil over 20% in Colombia and Venezuela in the 1980s) and protection of the banking sector reduced the return to financial assets and caused people to look to land as a hedge against inflation Thus the frontier was an escape valve for the capital of the rich (Figure 2)

Table 4 Selected macro indicators Brazil Colombia Venezuela

	Brazil	Colombia	Venezuela
Per cápita			
(constant 1980$)			
1970	1112	897	4839
1980	2019	1125	4100
Incidence of poverty[1]			
1970	49	45	25
1980	39	39	22
Illiteracy			
1970	34	19	24
1980	26	12	15
Infant Mortality (per 1000)			
1970 75	91	73	49
1980 85	71	41	39
Mechanization			
(No of ha/tractor)			
1970	205	221	182
1980	90	183	99
Urbanization (%)			
1970	56	57	72
1980	68	64	83
1990	77	70	91
Inflation rate[2]			
1971	12	18	4
1980	83	27	22
1990	2928	32	41

Households with income less than twice the basket of basic foods

[2] IMF International Financial Statistics 1981 Contraloría General de la Republica 1 994 Balance del cuatrienio Revista Económica Colombiana (July August)

Source CEPAL 1993 Anuario Estadístico de América Latina y El Caribe Edición 1992 United Nations

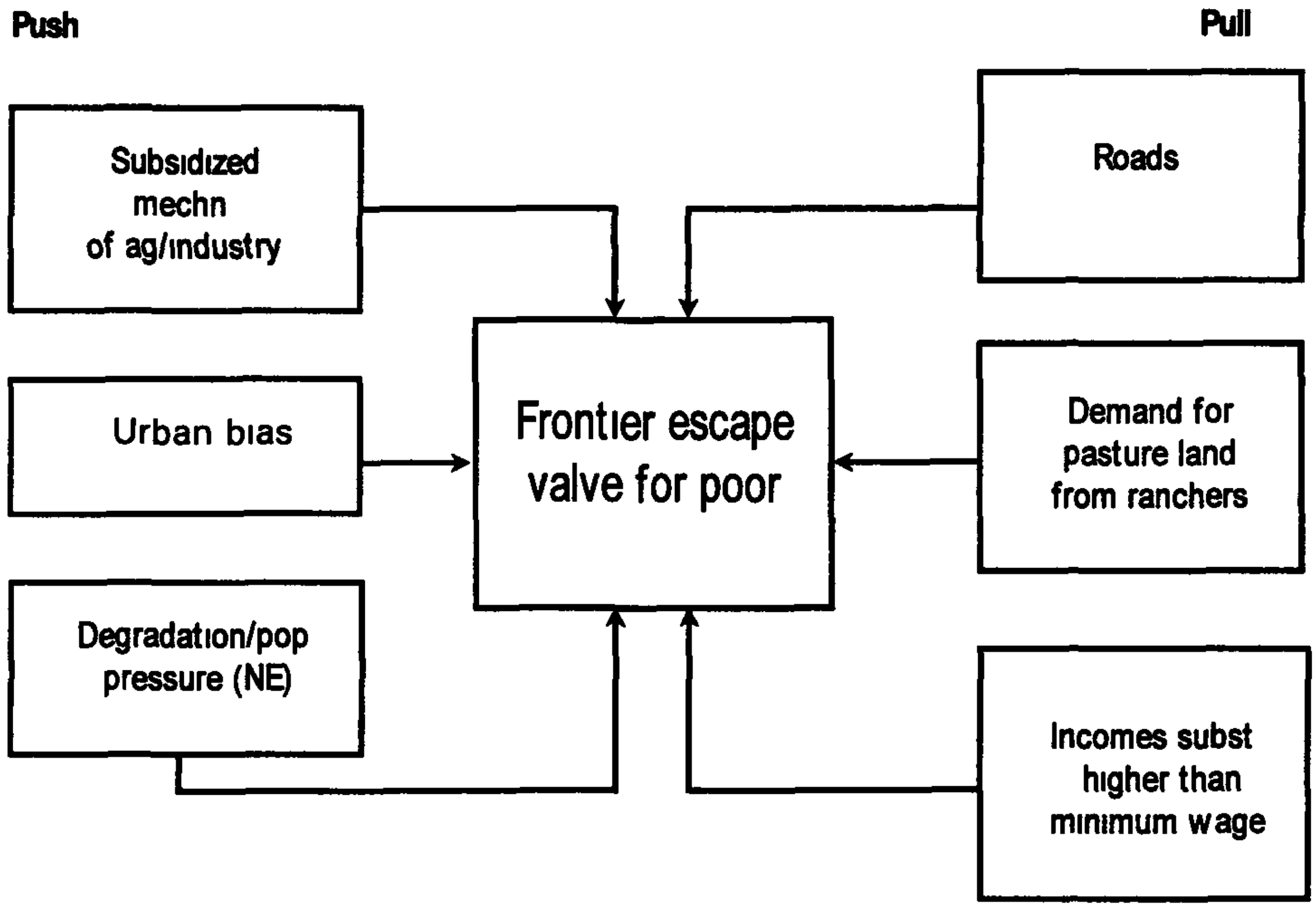

Figure 1 Causes of deforestation

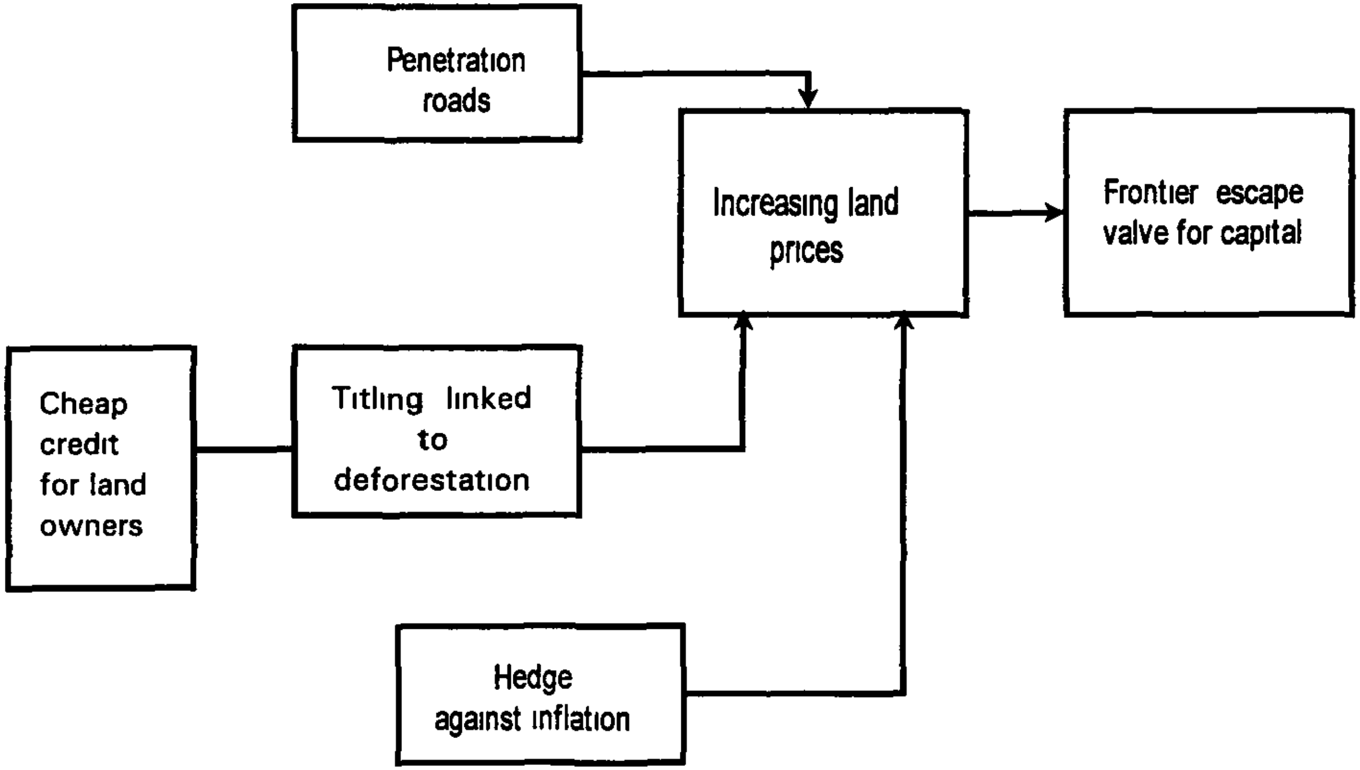

Figure 2 Causes of deforestation

The frontier is characterized by abundance of land relative to people high transport costs which reduce the profitability of economic activity minimal social services and poorly enforced property rights In view of these characteristics settlers at the extreme frontier are likely to have low levels of physical and human capital and therefore low opportunity costs Given the difficulties of operating a farm in the FM it is likely that these migrants are from other rural areas as opposed to being the urban poor Small scale settlers in the extreme frontier of the FM clear a few hectares of land and grow nutrient demanding annual crops such as rice and maize for food and cash for a few years As fertility declines pastures which are less nutrient demanding are established and new land is deforested for annual crops As the frontier matures and transport and government services improve people with higher levels of capital find it possible to cover their opportunity cost Given the poor social amenities these settlers are unlikely to reside at the frontier Extensive cattle ranching is their preferred form of land use as it requires low levels of investment and management Ranchers achieve savings in deforestation and pasture establishment costs are achieved by buying out and consolidating the pastures established by small scale holders Selling out to large scale ranchers also provides small holders with the capital to acquire and deforest a new piece of land Data show a positive relationship between farm turnover and economic performance Thus in addition to the push factors behind migration of the poor to the frontier the pull factors include the demand for pasture land from large scale ranchers and the construction of penetration roads which improve access to frontier areas Recent data also show that incomes of successful settlers are substantially above the minimum wage Thus land consolidation and transience of land use and land users is a characteristic feature of the frontier in the FM and results in enormous environmental costs both through deforestation and through degradation of pastures on large scale ranches where land values are too low to justify intensive management The availability of new frontiers through the construction of new penetration roads is a prerequisite for this phenomena to operate Satellite imagery show that deforestation has been heaviest along these roads In areas where government incentives for large scale ranching exist land acquisition and deforestation by people with higher opportunity costs occurs at the extreme frontier Absentee ownership and poor enforcement of property rights at the extreme frontier leads to squatting by people with lower opportunity costs The result is massive social conflict and exacerbation of land degradation because of uncertainty of land tenure and because speculation and not production is the main motive for holding land The description of the logic behind frontier expansion shows that although pasture is the dominant form of land use in the FM much of the land under pasture was initially cleared for growing annual crops It also implies that beef exports were not the driving force behind deforestation as has been alleged In fact data show that the Amazon barely produced enough beef for its own needs In Central America where exports were substantial pasture expansion and deforestation continued after exports declined in the 1980s The root causes of deforestation were opportunities at the frontier for land speculation and escape from poverty Once deforestation occurred pasture was the land use most in accordance with the logic of the frontier

The same frontier logic leads to very different patterns of land use in the savanna The nature of the soils make it difficult for early settlers to make a living from small holdings Early settlers therefore go to the areas along the river beds where the soil is relatively more fertile and grow crops such as cassava and beans which are more tolerant of low fertility Later settlers who arrive when the frontier is more mature establish extensive ranches on native savanna They do not bid earlier settlers off the land as the topography near the river beds is not conducive to mechanization and consolidation As the frontier matures in the savanna intensively managed pastures and field crops replace extensive native pastures Very large farms are fragmented to permit more intensive management Small scale farmers with some capital and entrepreneurial ability become better integrated into markets and develop into medium scale family farms buying out marginalized small holders who emigrate because employment opportunities are minimal in rural areas due to high levels of mechanization Employment opportunities in agribusiness in urban areas in the savanna increase but whether or not rural migrants have the human capital to take advantage of this is unknown Government intervention can alter these dynamics Subsidies for large scale ranching have led to better off migrants acquiring land at the extreme frontier for speculation purposes As in the FM the result is squatting social conflict and land degradation Subsidies such as uniform fuel and output prices have also led to expansion of intensive annual cropping in the extreme frontier These areas reverted back to extensive ranching when subsidies were removed

Thus we see that government policy including policy outside the agricultural sector was a major determinant of frontier expansion and land use patterns in both the savanna and FM

Emerging trends

In the last decade new trends indicate a reversal of some of the most damaging features of the past thus giving rise to a unique opportunity for effective resource management research

Remote sensing data from various sources now indicate a major reduction in deforestation rates in the Brazilian Amazon since the late 1980s A number of factors have reduced incentives for land speculation among which are the removal of incentives which increased land prices elimination of provisions linking land titling and deforestation and improvement in the returns to financial assets (Real interest rates in the 1992 1994 period in Brazil were as high as 23% to 43%) The construction of penetration roads has been reduced and government policy has changed from settlement to relatively tight control over deforestation In Colombia acquisition of land in the FM continued to provide opportunities for money laundering and cultivation of illicit crops The push factors leading to smallholder migration remained unchanged However population growth rates in the FM of both Brazil and Colombia declined This occurred because of declining national population growth rates and because of the development of cities which provided an alternative escape valve for the poor On the other hand there is evidence of an increase in mining and logging activities which lead to penetration roads which provide access to later migrants Recent data on frontier expansion in the savanna are not available but the common perception is that reduction of the speculative motive and the removal of uniform fuel and output prices has reduced frontier expansion in the cerrado In Colombia by contrast oil discoveries in the eastern savanna is leading to major road construction programs which are likely to lead to a major increase in agricultural development The recent economic crisis in Venezuela has destroyed confidence although the currency devaluation is reported to be increasing exports

In the field of technology development new opportunities for integrated ecosystem management between ecologists and conventional technology developers such as soil scientists and germplasm specialists are emerging A finding which is particularly relevant is that rain forests which ecologists had previously regarded as highly fragile and difficult to rehabilitate are now seen as resilient Data are now available to illustrate the importance of forest regeneration after human intervention Satellite imagery show that in Altamira Brazil secondary growth is the predominant form of land cover in deforested areas secondary growth is increasing rapidly and 42% of new agricultural land was created by clearing secondary growth (Table 2 columns 3 and 4) Studies show that secondary growth can be managed to enable the regenerated forest to fulfill many of the ecological functions of primary forests This provides opportunities for combining economic gain with environmental enhancement and may require major changes in technology development strategies For example a major focus of conventional technology development in the FM has been on preventing secondary growth for example by striving for pasture persistence These new findings show that secondary growth may have an important ecological function and that an important focus of research in the FM should be the enrichment of secondary growth with faster growing more valuable low volume species which could make settlers interested in regeneration and preservation of secondary forest as opposed to deforestation for crop and livestock production The regenerative capacity of land use systems could be enhanced by for example increasing carrying capacity with improved pastures while simultaneously lowering the extinction threshold of species through management practices which protect seed banks from grazing These concepts could lead for example to successional land use systems in FM with say annual cropping followed by pastures followed by forestry or silvopastoral systems which while fulfilling settlers objectives would also fulfill ecological functions

Complementing these new ecological paradigms are advances in information technologies and opportunities for knowledge intensive as opposed to energy intensive technologies through biotechnology new materials and new energy sources Another favorable development is that environmental perspectives are becoming increasingly important not only to the world community but also to national governments in Latin America as evidenced by newly established ministries of environment and the increasing importance being given to natural resource management in national research systems A number of innovative technologies which could be useful components in an integrated strategy for the management of these ecosystems have been developed Among them are acid tolerant rice and maize a persistent and productive legume for grass legume pastures and an integrated crop pasture system which in addition to increasing profitability and improving soil physical and chemical properties also appears to be acting as a net sink for carbon and could thus have a major role to play in minimizing the greenhouse effect An idea that is increasingly being put forward is that developing countries may be able to benefit from a new comparative advantage the provision of ecological services The idea is to use international trade between countries based on their comparative advantage to achieve global ecological targets Thus a developed country government or private sector company could purchase carbon storage services in developing countries in order to meet required carbon emission standards if these services were cheaper than at home The Amazon rain forest provides Latin American countries with an asset capable of providing substantial ecological services particularly the preservation of biodiversity and carbon storage According to an estimate by the World Bank the value of carbon storage in the Amazon rain forest ($976 to $7200/ha) is 2 to 30 times the value of forest land even if the value of carbon in pasture is subtracted The ability of crop pasture systems to act as a net carbon sink in the savanna provides another potential source of a comparative advantage in ecological services There are signs that an international carbon market may be developing In view of the agreement under the climate change convention to reduce carbon emissions to 1990 levels US utility companies are investigating opportunities for reducing emissions through trapping waste heat in India through reforestation in Mexico and through modernizing electricity generation in China The Costa Rican government is developing government guaranteed carbon storage certificates with the objective of trading them in international markets While participation in international markets for ecological services could provide important incentives for the adoption of ecologically sound land use systems problems raised with this concept include loss of national sovereignty and the high transactions costs of ensuring that ecological services are in fact provided Many of these problems can be overcome by having markets in short term rental contracts (as opposed to markets in land purchases) or by franchising contracts between local authorities and the world community Such mechanisms enable national land owners to select their own land use strategies as long as they meet specified environmental standards As the contracts are short term and renewable they provide land owners with an incentive to ensure that environmental standards are met Research can make an important contribution towards increasing comparative advantage in ecological services Development of land use systems that increase incomes while simultaneously providing ecological services (an example being the crop pasture technology) reduce the cost of providing ecological services and therefore increase comparative advantage Conversely increasing the profitability of competing land use systems which do not provide ecological services (say continuous monocropping with intensive tillage) will increase the incentive required to induce adoption of ecologically sound land use systems and thus reduce comparative advantage in the market for ecological services Thus research priorities need to be carefully coordinated with the development of markets for ecological services The new developments described above interact to provide a unique opportunity for effective resource management (Figure 3) Transience of small settlers which is a major cause of deforestation occurs because the cost of gaining access to a new plot is less than the income lost because of yield decline on the old plot Research can stabilize yield decline on the old plot Increasing the cost of a new plot is however difficult to achieve through research and if the cost of acquiring a new plot remains low deforestation is likely to continue Changes in policy are however increasing the cost of a new plot The construction of penetration roads is being reduced New plots were financed by selling out old pasture plots to large scale ranchers The demand for pasture land from large scale ranchers is however being reduced because the speculative motive for land acquisition is declining as a result of policy changes At the same time reduction of inflation which benefits the poor should reduce the attractions of the frontier for small scale settlers The new ecological paradigms also provide ideas for technologies such as enriched secondary forests which could provide incentives for long term settlement on the same plot Complementing this is the emerging market in ecological services which if complemented with the right technologies could provide important incentives for the adoption of sustainable land use practices In addition the savanna may be able to make an important contribution towards reducing deforestation As indicated earlier the savanna appears to have a comparative advantage in certain crops and livestock which could be further enhanced by recent technological advances If technologies for sustainable development of the savanna are adopted capital investment in savanna agriculture could divert capital away from the FM and thus reduce the demand for large scale ranches in the FM In addition improved infrastructure and intensification of agriculture in the savanna could stimulate the development of urban centers in the savanna which could provide employment opportunities in agribusiness and thus reduce the attractions of the frontier for the poor Simultaneously the savanna could contribute to environmental improvement through carbon sequestration by crop pasture land use systems whose adoption could be enhanced by the emerging market in ecological services

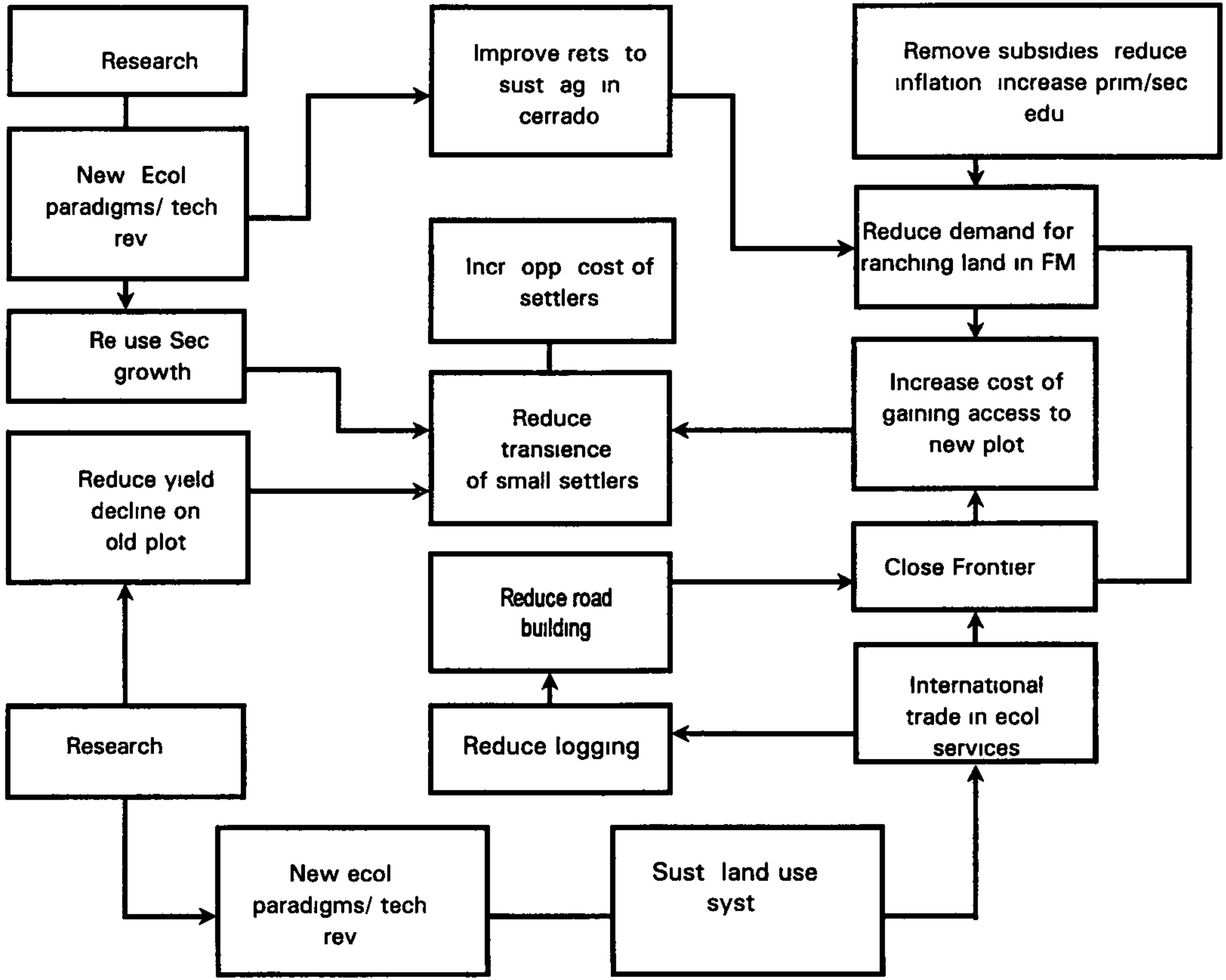

Figure 3 A unique opportunity for resource management

A vision for the year 2020

On the basis of our analysis of determinants of land use trends we have specified three scenarios for government policy and two technology development strategies We then use a land use model to simulate land use changes up to the year 2020 for the FM and savanna in Brazil for different combinations of government policy and technology development strategies

Government Policy
Scenario 1

Opening up of the economy increases imports and puts pressure on increasing agricultural exports Agricultural development of the cerrado is seen as a mechanism for achieving this Expansion of infrastructure into the cerrado continues Ad hoc regulatory mechanisms are used to protect areas of the cerrado from agricultural expansion but prove to be difficult to enforce Inflation continues to be unstable and high because of failure to achieve a solid fiscal position Uncertainty about the return on financial assets results in high speculative demand for land The currency becomes overvalued and reduces the profitability of exports Urban bias continues and leads to increased urbanization resulting in increased levels of urban crime and unemployment Attempts are made to improve income distribution by imposing contractual obligations on employers of agricultural and industrial labor But this makes labor more costly and reduces employment Government becomes aware of the link between roads settlement and deforestation Construction of penetration roads into the FM is slowed down subsidies for large scale cattle ranching are removed Land titling is no longer linked to deforestation Mining and logging continues because of lobbies and these activities leave behind access roads Government continues to allow some road building in the Amazon because of military reasons or because of local lobbies based on reasons of economic development

Scenario 2

Same as Scenario 1 except for fiscal balance stable moderate inflation political and economic stability which reduces the speculative demand for land and benefits the poor through increasing their purchasing power and creating employment opportunities A stable real exchange rate reduces pressure on agricultural exports as a tool for balancing the current account and increases the profitability of exports

Scenario 3

Same as scenario 2 plus social programs oriented towards improving the welfare of the poor such as greater access to primary and secondary education improvement of social amenities in rural areas dismantling of contractual obligations on employers of labor to encourage higher levels of labor intensity These measures are expected to increase the opportunity cost to the poor of migrating to the extreme frontier At mature frontiers there is better enforcement of property rights and better provision of social amenities to reduce absenteeism squatting and social conflict Construction of penetration roads is diminished to reduce the opening up of new frontiers in both the FM and the cerrado but intensive farm to market road networks are constructed in mature frontier areas in both ecosystems which reduce the cost of inputs and the cost of marketing output Government services and infrastructure are improved in urban areas within mature frontiers in the FM and savanna This stimulates local processing and distribution of savanna and FM products These measures provide the policy environment for the development of land use systems which are profitable as well as ecologically sound International markets in ecological services develop and this makes the government aware of the concrete benefits of protecting the environment in both ecosystems This creates the political will for integrating environmental considerations with economic political and military objectives for enacting environmental measures and for resisting mining and logging lobbies

Scenario 1 approximates the situation that is likely to prevail in Brazil if the new stabilization plan fails Current developments however indicate that the most likely outcome is scenario 2 Scenario 3 depicts further policy changes which we would like to see Colombia too is moving towards scenario 2 The discovery of oil in the eastern savanna is leading to major improvements in infrastructure and is likely to lead to major advances in agricultural development in the savanna This however could be seriously jeopardized by rural security problems due to guerrilla activity If the government is unable to control drug trafficking acquisition of land for money laundering and cultivation and processing of illicit drugs will continue and non productive motives for land acquisition will remain Another obstacle to the achievement of scenario 2 could be the appreciation of the currency in real terms which would reduce the competitiveness of exports and thus hinder the development of the savanna and impede the creation of jobs in agribusiness and in the nonagricultural sector Appreciation of the currency in real terms is likely if the government is unable to reduce inflation and repatriation of income from drug trafficking Higher incomes from petroleum exports are likely to contribute to the upward pressure on the exchange rate The situation in Venezuela is the least optimistic Unless major changes in policy are introduced the situation in the short run is most likely to approximate scenario 1 although the currency has depreciated sharply because of lack of confidence in the economy and is likely to remain weak This could jeopardize free trade agreements with other Latin American countries and also adversely affect the exports of these countries The economy is likely to remain highly regulated thus building up serious structural adjustment problems for the future These policies are however unlikely to be sustainable and in the medium term there could be signs of an emerging scenario 2

Technology development strategy

Scenario A

A component technology approach with research oriented towards improving the productivity of particular commodities such as crops and livestock Activities include the development of agroecologically adapted varieties including varieties which reduce the requirement of external inputs management of biotic and abiotic constraints to the increased productivity of the mandate commodities identification of socioeconomic constraints to technology adoption such as inefficient markets Consequences of new technologies are monitored to avoid the development of technologies which impact negatively on non productivity aspects such as equity and nutrition The main focus is on technological solutions related to mandate commodities with other components policies and institutions taken as given

Scenario B

This is the ecoregional approach where the mandate is an agroecological zone within a geographical region The objective is to identify an appropriate role for agroecosystems within the ecoregion taking national and international considerations into account and to stimulate the research required to achieve that vision The interaction between technology policies and institutions is explicitly recognized and recommendations for policy and institutional reform are an integral part of the approach The approach therefore requires close collaboration between different categories of research bodies including national and international institutes and the private sector as well as implementors of research findings *such as NGOs and policy* makers In addition to productivity and equity protection of the environment is an important objective including the identification of ecosystems where agricultural exploitation is inappropriate

Forest Margin

In this ecosystem the overall strategy is to reconcile the international community s objective of halting deforestation with the reluctance of national governments to sacrifice the economic potential of the FM for the sake of ecological benefits that accrue to the world community as a whole Technology development will be based on a land use plan for the FM which exploits the diversity of environments within the FM including both cleared areas and surrounding forest areas This will be based on a sound understanding of land use dynamics and will include policy recommendations on issues such as infrastructure protected areas reforestation schemes and participation in global markets for ecological services Technology development will include

a) Intensification and stabilization of agriculture on small holder plots particularly food crop plots to reduce transience Research now suggests that continuous cropping is possible *with fertilizer use Improved farm to market roads* will however be require to make this economically viable Penetration road construction will have to be halted to make these technologies adoptable

b) The desirability of intensifying and stabilizing small holder livestock production will have to be *carefully considered as aspects of these technologies may also be applicable* to extensive large scale cattle ranches and may therefore encourage land consolidation and promote deforestation Technologies which improve milk production such as genetic improvement of dairy cattle species are less likely to have this effect

c) Successional land use systems on small holder plots with pastures *managed to encourage* enriched secondary growth and the development of agroforestry or agrosilvopastoral systems This may anchor small holders to their plots

d) Study of indigenous systems for insights into agricultural systems compatible with forest regeneration

e) Increased profitability of sustainable forestry systems non timber forest products rubbertapping sustainable selective logging and the management of these systems to enhance their capacity to provide ecological services

f) Regeneration of degraded areas with reforestation agroforestry or agrosilvopastoral systems

g) Management of secondary growth to reduce the cost of recultivation versus the cost of moving to a new plot

h) Labor intensive agribusiness technologies in urban areas of the FM such as the processing and distribution of FM products such as non timber forest products and milk This is expected to increase the profitability of these commodities while providing alternative employment opportunities for potential deforesters

Savanna

In this ecosystem the overall strategy is to provide an outlet for the government s economic objectives thus relieving pressure for exploiting the FM for agriculture and extractive activities Rural and urban development in the savanna is also visualized as diverting venture capital from the FM while agribusiness development may absorb migrants from rural areas who may otherwise have migrated to the FM The objective is to achieve this development while protecting the environment This is particularly important as the savanna contains semideciduous and gallery forest and is part of the watershed of three major rivers Thus savanna development could have environmental impacts both within and outside the savanna As in the FM technology development will be based on a land use plan derived from a sound understanding of land use dynamics Technology development will include

a) Increase returns to capital investment in the savanna by developing a range of technological options with progressively increasing levels of capital and management intensity targeted to a range of environments varying from moderate to high levels of infrastructure and land values The extensive end of this continuum includes technologies for managing native savanna grasses with or without small areas of improved pasture At the intensive end it includes integrated ley farming systems with technological innovations enhancing their profitability and carbon sequestration capacity Simultaneously technology development on competing land use systems which lead to soil degradation and do not provide ecological services (such as monocropping with continuous heavy tillage) will be de emphasized

b) Development of technologies for sustainable forestry in areas of existing semi deciduous forests Agroforestry planted forest fruit and nut trees agrosilvopastoral systems particularly in areas where destruction of semi deciduous forests has taken place Emphasis will be on both profitability and ecological functions This is expected to enhance adoption by increasing comparative advantage in markets for ecological services

c) Technologies for recuperation of degraded areas including ley farming systems in intensified areas

d) Investigation of the off site effects of intensification such as siltation and pollution of rivers technologies to reduce their impact and institutional mechanisms for internalizing externalities

e) Labor intensive technologies for processing and distribution of savanna products in urban areas of the savanna

f) Technologies for commodities in which the relative resource endowments of small scale farmers have a comparative advantage include vegetable production dairying and subsistence production of cassava and beans This is expected to prevent outmigration of small scale farmers Particular emphasis will be placed on the environmental effects of small scale farming because of their location along rivers and gallery forests Technologies for sustainable exploitation of gallery forests and for increasing the role of tree crops in systems in deforested areas will be developed with emphasis on their compatibility with the resource endowments of small scale farmers

g) Land use planning will identify areas whose main function will be the preservation of plant and animal biodiversity Ideally these will coincide with remote areas and areas of low biophysical potential for agricultural exploitation Technology development in these areas will be limited to recuperation of the ecological functions of degraded areas and identification and evaluation of the ecological services provided by native grasses semi deciduous and gallery forests Prevention of agricultural exploitation of these areas will require the absence of penetration roads Participation of these areas in markets for ecological services may contribute to their preservation as may ecotourism

Technology development strategy A approximates past history The adoption of ecoregional mandates by international research centers in the region the new emphasis on resource management issues in national research systems and NGOs in the region indicate however that the realization of strategy B is highly probable provided sustained donor commitment to activities of this nature are available Given the long term nature of most of these activities the identification of concrete intermediate outputs will be essential for obtaining sustained funding

SIMULATING LAND USE CHANGE

A simulation model divides land in each ecosystem into different ecological categories with different productive capacities and different ecological functions Movement of land between different categories is simulated the rate of change being defined by the scenarios Ideally the model should contain a socioeconomic sub model for simulating the rate of change in land use categories under each scenario This is not available at the present time and rates of response to policy measures and technology development are derived from the judgement of the authors As detailed field work is carried out data will be available for more accurate estimates of rates of change The model is run up to the year 2020 for each combination of policy and technology development scenarios A comparison between scenarios 3A and 1A shows what policy improvements can achieve with a component technology approach The difference between 1A and 1B shows what a shift to an ecoregional approach can achieve in the absence of policy improvements 3B is the ideal scenario which shows what the ecoregional approach can achieve in the presence of favorable policy The difference between 3A and 3B shows the incremental contribution of the ecoregional approach over the contribution of policy

Preliminary results are presented In particular it should be pointed out that results on only broad categories of land use change are available at this time Analysis of the disaggregation of these categories and the environmental and socioeconomic consequences are still underway Thus while results on changes in altered land are available analysis of its breakdown into categories such as regenerated forest abandoned land and the consequences on the environment employment etc are still under way At this stage the model has been run separately for the cerrado and FM without interactions between the two although we hypothesize that these are important

The results available so far show the following

Cerrado

a) Frontier expansion is most rapid under scenario 1A because of speculative motives for holding land and because the pressure to increase exports leads to the construction of penetration roads By 2020 only 6% of the land is in its natural state Much of the expansion occurs into marginal areas unsuitable for agricultural exploitation leading to resource degradation Frontier expansion declines in 2A and 2B because the speculative motive declines and further in 3A and 3B (15% to 19% of the land area) when penetration road construction declines because governments become aware of the value of environmental services In 3B there is a qualitative improvement in the natural area because the land use plan identifies the most appropriate areas from both the conservation and economic points of view

b) Grain production increases sharply in all scenarios The increase is least in 1A (from 6 2 m t to 14 1 m t) because the speculative motive leads to land degradation Although recuperation technologies are developed in 1B they are not adopted because speculation and not production is the main motive for land acquisition Production increases are higher in 2A and 2B and highest in 3A and 3B (23 m t to 30 m t) because land values increase due to the closing of the frontier and technologies for recuperating land are available In addition in 3B the increase is achieved with a reduction in offsite effects because of the existence of technologies and institutional mechanisms for internalizing externalities

c) Planted pastures increase from 26 m ha to about 50 m ha and sequester 150 to 750 m t C/ha The number of cattle per head increases most in scenarios 1A and 1B (from 32 to around 70 m heads) because of rapid frontier expansion In 3A and 3B cattle numbers are lower (about 60 m heads) but stocking rates and production per animal are higher because of policies such as improved farm to market roads and the development of appropriate technologies

d) By 2020 wood production is highest in 3B (81 m t) because of the existence of 18 m ha of agrosilvopastoral systems which store 85 t C/ha In the A scenarios very little adoption occurs because the component technology approach gives insufficient attention to understanding the dynamics of land use systems and is therefore unable to identify appropriate opportunities for technological interventions In 1B and 2B although the ecoregional approach leads to the development of appropriate technological interventions adoption does not occur because of unfavorable policies which lead to land speculation and frontier expansion and therefore promote short termism Also in the A scenarios the wood production comes from deforestation whereas in 3B it is from sustainable systems

Forest Margin

a) With favorable policies and an ecoregional technology development strategy deforestation is 37% lower in 2020 than it would be with policy scenario 1 and a component technology development approach

b) Without favorable policies the shift to the ecoregional approach achieves little change in land use in quantitative terms Under policy scenario 1 the area of natural ecosystem (275 m ha) is unchanged when the ecoregional approach is introduced because of the speculative motive and the lack of policies to increase the opportunity cost of potential migrants to the frontier

c) In scenario 3B 19 m ha of altered land are converted to a variety of tree crop based systems Forest regeneration also increases sharply aided by the new ecological paradigms The ecoregional approach identifies appropriate systems which meet objectives of settlers while at the same time providing ecological services Adoption occurs because farm to market roads increase profitability and because participation in markets for ecological services provides a further incentive for adoption

This enables national governments to obtain economic benefits from the FM while at the same time contributing to environmental improvement

CONCLUSIONS

A thorough understanding of land use dynamics is essential for developing a resource management strategy Analysis of land use change in the FM and savanna of Latin America based on secondary data and literature review showed that many of the driving forces originate at the national policy level both within and outside the agricultural sector as well at the global level An essential component of a resource management strategy for these ecosystems therefore should be recommendations for policy and institutional reform The analysis also revealed that for effective ecosystem management technology development will have to move away from the conventional approach of developing productive components such as crops livestock and tree species to a broader approach that includes aspects such as forest regeneration management of secondary growth non timber forest products identification of conservation areas development of agribusiness technologies and enhancement of comparative advantage in markets for ecological services A land use simulation model revealed that even this broader approach to technology development is unlikely to be effective in the absence of favorable economic social and environmental policies Fortunately however many unfavorable policies have been dismantled deforestation has sharply decreased and speculative frontier expansion in the savanna has decreased particularly in Brazil Reinforcing this is the rise of new ecological paradigms which provide new opportunities for combining environmental improvement with productive land use Other favorable developments are the newly established resource management programs in national research systems and Ministries of the Environment in Latin America A development of major significance is the emerging international trade in ecological services Both the savanna and FM of Latin America appear to have a comparative advantage in this field and if supported by an appropriate technology development strategy this could be a key mechanism for inducing adoption of environmentally sound practices While these developments go a long way towards providing a favorable background for effective ecosystem management further policy and institutional changes are required such as improved access to primary and secondary education for the poor improved farm to market roads control of drug trafficking improvement of peace and order and the political will to withstand the pressures of mining and logging lobbies Our land use model indicates that these policy and institutional changes and a broad based ecoregional technology development strategy may make it possible for national governments to obtain economic benefit from the FM while contributing globally to the protection of the environment The strategy for the savanna should be developed in close conjunction with that for the FM

The analysis shows that substantial increases in crop livestock and tree products are possible from the savanna Thus the savanna could provide an outlet for the economic objectives of national governments and for venture capital while relieving pressure for exploiting the FM A careful land use plan will be essential for achieving this with accelerated rural and urban development in certain areas for attracting venture capital combined with labor absorption in agribusiness in urban areas of the savanna and the prevention of agricultural expansion in remote marginal areas The strategy will have to be based on a sound understanding of the ecological implications of savanna intensification as the savanna is part of the watershed of three major rivers and it is particularly notable that the practices of small scale farmers may play a major role in these externalities Overall our analysis indicates that the present constellation of events relating to the savanna and FM of Latin America is particularly favorable for achieving major improvements in the management of these ecosystems We therefore have a unique opportunity for successful and effective resource management research

TA02 CHARACTERIZATION OF SLASH AND BURN AGRICULTURE AND DEFORESTATION IN PEDRO PEIXOTO ACRE AND THEOBROMA RONDONIA BRAZIL *Sam Fujisaka*

Tropical deforestation due in part to slash and burn agriculture contributes to global warming via burning and release of CO_2 into the atmosphere and Brazil is now the fourth atmospheric carbon contributor after the US ex Soviet Union and China Deforestation is also leading to losses of genetic and cultural diversity Decreasing transpiration and precipitation within and outside of areas cleared may also be a consequence of deforestation

With funding from the Global Environmental Fund (GEF) a project Alternatives to Slash and Burn (ASB) was initiated to address such problems and as this paper reports farmer settlers in the government colonization projects of Pedro Peixoto in the Amazonian state of Acre and in Theobroma Rondonia were interviewed as a part of activities to characterize local systems and system dynamics Funding for this stage of systems characterization was also provided by the Inter American Development Bank

The project currently includes sites in Cameroon and Indonesia and is a collaborative effort among national research systems non government organizations and at the international level the International Centre for Research on Agroforestry (ICRAF) CIAT the International Food Policy Research Institute (IFPRI) and the Tropical Soil Biology and Fertility Programme (TSBF) The project seeks to develop technical and policy alternatives to slash and burn agriculture which would have effects of decreasing global rates of deforestation while enhancing the well being of forest users

Settlement in colonization projects such as Pedro Peixoto and Theobroma has been facilitated by government policies to populate frontier areas in the Amazon road construction and direct and indirect subsidies Data presented in compete form under Project UT04 addresses the dynamics of deforestation at the farm level i e farmer decision making in light of constraints and opportunities afforded by the local agroecosystem and within the context of relevant local regional national and international policies

The conclusions of that research were

Deforestation at the farm level appears to continue at a relatively steady pace averaging somewhat more than one ha per year per family in the two colonies Settlers still had more than half of their lands in forest and for the most part can and probably will continue to slash burn and cultivate more primary forest as their currently most (economically) viable option Two main factors driving land clearing at the farm level were the need to produce food crops and incentives to convert land into pasture In terms of food production farmers consumed and sold rice and to a lesser extent beans maize and cassava (or cassava meal) Rice cultivation may drive some deforestation in that although farmers usually planted a cleared field for two or three years they could not for technical reasons sow rice other than in the first year after clearing As such a research priority of the ASB project may be to determine if and under which management alternatives could rice production be made more sustainable (acknowledging the caveat that any improvement in productivity may lead to greater economic attractiveness of the respective enterprise and thereby invite more deforestation or other forms of resource over exploitation)

Farmers were clearly motivated to convert cleared lands into pasture because of real or at least perceived resulting increases in land values Farmers not only maintained cattle as standing bank accounts and obtained cash from sales of animals and milk but built savings by investing time and resources in fencing corrals ponds and other ranching necessities As observed throughout the two sites local ranchers and urban based speculators have purchased continuous blocks of colonists parcels to form new ranches or to expand the size of adjacent ranches and payments were reportedly much higher for cleared vs forested portions of parcels

Farmers pasture management practices consisted of introducing mainly Brachiaria spp annual pasture burning and rotation of animals to different pastures In spite of generally low stocking rates there were substantial areas of poor and degraded pastures and pasture lands at both sites Although construction of new cheese processing plants near Theobroma may result in intensification at that site extensive and low input cattle and pasture management appear to be the current norm for both sites Whether or not improved pasture technologies are possible and would be appropriate to farmers current conditions is another researchable issue

Conversion of cleared forest land to pasture has meant that at least in the colonies studied that there was relatively little land placed in fallow with resulting secondary regrowth and forest regeneration An implication is that research on improved fallows may either result in making fallows more attractive to farmers (as is hoped) because of more rapid regeneration and better maintenance of soil organic matter or farmers may be uninterested in improved fallows because conversion to pasture is by far the preferred land use after cultivation

Theobroma farmers practiced agroforestry in the sense that they had significant areas of perennial crops mainly coffee and cacao Pedro Peixoto settlers have had less favorable experiences regarding perennials citing poor prices and/or markets as major constraints Some Pedro Peixoto farmers had been encouraged (provided with credit) to plant urucu (Bixa orellana used to produce red dye) When the trees started to produce prices for the product fell to the point that farmers could not afford to harvest and lost their investments Currently settlers in Theobroma were being provided credit to grow acerola (Malpighia punicifolia) Although they were promised a future market for all that they produce schemes to introduce or encourage perennial crops or agroforestry remain risky

A resource that was largely not available in the systems examined is indigenous technical knowledge of the type usually associated with shifting cultivators Farmers were asked about their soil and land classification and corresponding use systems Although they distinguished soils by color and texture and called attention to lands either having a sub surface compacted layer or low waterlogged areas they did not employ such distinctions in choosing areas to clear and cultivate Farmers simply cleared land in steady sequence from the areas closest to the roads and houses and towards the rear of their parcels Although a few named plant species which indicated soil impoverishment and others which indicated fallow regeneration most farmers appeared to have little concept of use of fallows for biomass (and subsequent soil fertility) regeneration or of (as mentioned) the use of fire to release nutrients for crops use Only a few Theobroma farmers mentioned that there were medicinal plants that could be harvested from the forest

The heartening news is that rates of deforestation in the Amazon Basin appear to be decreasing due to fewer incentives to large corporations to invest in cattle ranching a virtual end to a period of road building to open up the Amazon and to protect frontier areas and a decline in government assisted colonization programs for the rural poor Secondary forests have shown relatively high rates of regeneration both after slash and burn agriculture and after abandonment of degraded pastures and a significant proportion of deforestation for shifting cultivation is now of secondary rather than primary forest

On the other hand deforestation and/or consolidation of colonists parcels to form or expand ranches has continued with ranches now being formed less by frontier risk takers and more by urban speculators in areas where land prices have risen and where government can protect such investment The evidence presented suggests that deforestation on colonists parcels continues at an apparent steady pace driven by food production needs and by incentives similar to those now pushing formation of larger ranches

To some extent the characterization data suggest the need for on farm research to develop alternatives to slash and burn agriculture Such research already underway or planned needs to examine the possibility of making rice production more sustainable (and thereby hopefully reducing demand for newly cleared forest) improving (i e intensifying to the degree appropriate) pasture and cattle management introducing or encouraging more perennial cropping and agroforestry and improving fallows At the same time and equally or more importantly this analysis recognizes the importance to deforestation of national policies regarding road construction credit tax incentives frontier settlement land tenure and the rural poor Development of alternatives will need to include substantial attention to policies and future policy options

COMPLEMENTARY SUBPROJECTS UT51 (UT04) A DIAGNOSTIC STUDY OF AGRICULTURAL LAND USE IN THE SOUTHWEST BRAZILIAN AMAZON AND TA51 (TA02) ALTERNATIVES TO SLASH AND BURN

Sam Fujisaka (LM)

The purpose of CIAT s work in the forest margins is to develop options for arresting soil nutrient depletion as well as policy options for promoting stabilization of shifting cultivation

The purpose of UT51 (a complementary subproject of UT04 Ecoregional Research and Exploratory Activities) is to analyze the social cultural political and ecological factors that shape the development of land use patterns in colonized areas of the states of Acre and Rondonia Brazil The donor for this project is IDB Research partners include EMBRAPA (in Acre and in Rondonia) PESACRE ICRAF and IFPRI (Steve Vosti) This subproject was funded for 1994 1995 only

The purpose of TA51 a complementary subproject of TA01 Prototype Sustainable Cropping Systems for the Forest margins is to design sustainable agrosilvopastoral systems for deforested areas of the Amazon Basin This report covers research on intial system characterization being conducted at each of three sites included in the Global initiative on Alternatives to Slash and Burn Agriculture (ASB) funded by GEF and coordinated globally by ICRAF and by CIAT in Latin America The purpose of the ASB is to develop technical and policy alternatives which would help to decrease rates of tropical deforestation while enhancing the well being of forest resource users Research partners include EMBRAPA (in Acre and in Rondonia) PESACRE ICRAF IFPRI (Steve Vosti) CIFOR and TSBF

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With funding from the Global Environmental Fund (GEF) a project Alternatives to Slash and Burn (ASB) was initiated to address such problems and as this paper reports farmer settlers in the government colonization projects of Pedro Peixoto in the Amazonian state of Acre and in Theobroma Rondonia were interviewed as a part of activities to characterize local systems and system dynamics The project currently includes sites in Camaroon and Indonesia and is a collaborative effort among national research systems non government organizations and at the international level the International Centre for Research on Agroforestry (ICRAF) CIAT the International Food Policy Research Institute (IFPRI) and the Tropical Soil Biology and Fertility Programme (TSBF) The project seeks to develop technical and policy alternatives to slash and burn agriculture which would have effects of decreasing global rates of deforestation while enhancing the well being of forest users Settlement in colonization projects such as Pedro Peixoto and Theobroma has been facilitated by government policies to populate frontier areas in the Amazon road construction and direct and indirect subsidies Data presented in this paper addresses the dynamics of deforestation at the farm level i e farmer decision making in light of constraints and opportunities afforded by the local agroecosystem and within the context of relevant local regional national and international policies

INTRODUCTION DEFORESTATION IN THE AMAZON Rates of Deforestation Compared to Asia and Africa deforestation has been highest in Latin America in both absolute area (43 000 km^2/year) and percent of forest area cleared (0 64%/year) Of Latin American forests standing in 1850 370 million ha or 28% were converted by 1985 44% to pasture 25% to cropland 20% degraded and 10% to shifting cultivation Recent analysis of satellite data indicates that some 230 000 km^2 of the Brazilian Amazon is deforested and that 588 000 km^2 are affected if edge effects of one km into adjacent areas of forest are considered Deforestation in the Brazilian Amazon has been highest in Rondonia and Mato Grosso followed by western Maranhao Acre and northern Goias Shifting cultivation (slash and burn agriculture) was thought to account for 1 8 million ha or 32% of tropical American deforestation taking place in 1980 Causes of Amazonian deforestation 1960 1985 Interlinked factors contributing to deforestation up to a decade ago included road building land conversion to pasture and cattle ranching (and associated policies) demand for land by the rural poor credit and tenure policies which equated land improvements with clearing and land speculation (especially in a highly inflationary economy)

Roads opened the Amazon to settlement and land to deforestation The Brasilia Belem highway was completed in 1960 The then military government made the Amazon the focus of growth in 1964 BR364 between Porto Velho in Rondonia and Cuiaba in the south was completed in 1965 and improved in 1969 The government decided to build the Trans Amazon highway in 1970 and various sections were completed between 1972 and 1976 Deforestation in the Amazon has been the heaviest along these roads

Over 10 million ha of forest were converted to pasture from 1960 to 1990 The Agency for the Development of Amazonia (SUDAM) was established in 1966 largely to facilitate private investments in the Amazon through tax incentives with most support granted to large ranches and corporations Ranches now cover 8 4 million ha average 24 000 ha each but employ only one cowboy per every 300 ha and were profitable only with full tax advantages and at considerable social costs of 0 5 ton of rainforest per quarter pound of hamburger Beef produced however was not for export to the US for *its fast food industry as Hecht proposed* and as was the case in Central America Although beef sufficient for the same quarter pound hamburger cost US $0 26 to produce in the Amazon with $ 0 22 coming from subsidies the Amazon has barely produced enough beef for its own needs

Related policies that contributed to deforestation were exemptions of agricultural incomes from taxation *rules determining security of land claims which encouraged clearing* progressive land taxes encouraging conversion to pasture credit schemes subsidising corporate livestock ranches and tax breaks for wood products industries

The rural poor were pushed to the frontier areas in search of land 4 5% of Brazil s land owners hold 81% of the country s farmland while 70% of rural households are landless In *the period 1963 73 Brazil shifted from* inward oriented import substitution policies to modified outward oriented export substitution characterized by area expansion domestically produced inputs mechanization through credit increased output and land concentration and coffee eradication The period 1971 80 then saw a high expansion of agricultural exports and wealth concentration aided by high inflation combined with low fixed interest rates for a few borrowers Mechanization of soybean wheat and sugar cane production had the effect of driving the rural poor out of Brazil s populous and developed center south region In that area soybean became a major crop and labor intensive small scale agriculture was replaced by energy and machine intensive cultivation

Brazil s National Institute for Colonization and Agrarian Reform (INCRA) instituted a Program for National Integration (PIN) in 1970 to assist the rural poor High rates of migration to Rondonia including spontaneous migration and land invasions resulted in five million ha (21% of the state s land area) given to settlers by 1977 Forest clearing reached 17% of the state by 1987 and farmers with rural credit cleared 25% more forest than those without Problems such as lack of all weather access roads unsuitable seed early rains lack of planting materials for perennial crops and insecure titles as well as the oil crisis in 1973 however led the government to shift from supporting small farmers via colonization schemes to (again) aiding large operators in 1974 Other factors contributing to Amazonian deforestation have included displacement and resettlement of farmers from earlier settled areas in the north as soils were depleted or as demands for land by new speculators increased logging and wood processing and mining and use of timber for fuel for smelting

Deforestation since 1985

Some of the major incentives provided to large corporations and cattle ranches were eliminated in 1985 as Brazil suffered from recession and hyperinflation Although cause and effect relationships are difficult to establish recent analysis of remote sensing data shows that rates of Amazonian deforestation have been decreasing from 8 0 million ha in 1987 to 1 8 million ha in 1989 1 4 million ha in 1990 and to 1 1 million ha in 1991 On the other hand two thirds of deforestation due to ranching has occurred without SUDAM incentives and explanatory factors appear to be a) that new demands for (cleared) frontier lands by urban based land speculators have appeared as frontier government has strengthened to the extent that it can protect property rights (as opposed to ranchers having to finance private armies to maintain their land claims) and b) that cattle ranching is economically viable under current land prices

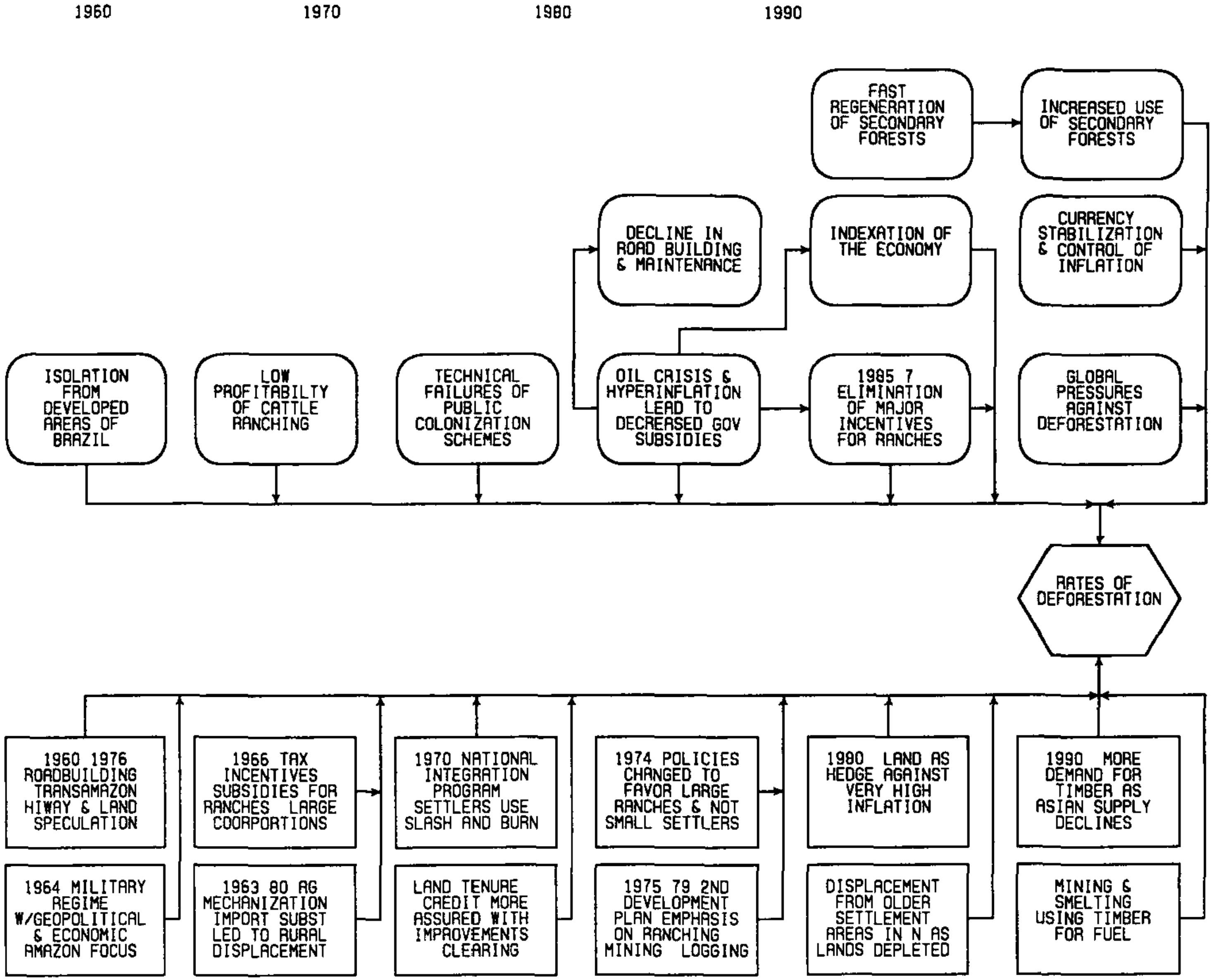
The various factors contributing to or tending to diminish deforestation in the Amazon Basin over time are shown in Figure 1

Optimistic viewpoints in the search for alternatives Optimistic findings have emerged along with the observed decreasing rates of deforestation First forests may be more resiliant and may rebound from disturbances more quickly and completely than previously thought Second secondary forests globally are being formed at about nine million ha per year and now account for 40% of total forest area and third much of currently observed deforestation is of secondary rather than primary growth As a result of such resiliance several researchers have proposed improved management of secondary forests and encouragement of natural forest regeneration

Other researchers have described the diversity of environments within the Amazon Basin and suggested land classification and zoning as starting points for improved land use and management

Although there is evidence that soil fertility under cattle pastures in the Amazon cannot be maintained research has also suggested that sustainability is possible with improved pasture species Contrary to earlier views of ecologists research also suggested that continuous cropping is possible with fertilizer use Agroforestry has also been suggested as an appropriate land use and even steam sawmills and stewardship rather than ownership were suggested as appropriate and needed for the Amazon

FIGURE 1 POLICIES & OTHER FACTORS LEADING TO GREATER AND/OR LESSER DEFORESTATION OVER TIME IN THE AMAZON



People also solve their own problems With deforestation of their parcels settlers in the Bolivian Amazon were observed to eventually reach a crises stage due to soil nutrient depletion weeds decreasing yields and increasing costs but then (some) successfully responded by turning to mechanization cattle or perennial crops thereby escaping to a consolidated stage with markedly higher incomes

THE RESEARCH SITES

Acre and Rondonia The state of Acre covers 153 000 km^2 The area of Rondonia is 239 000 km^2 Acre is drained by the Rio Purus and Rio Jurua while Rondonia is drained by the Rio Madeira Climate is warm and humid tropical with a rainy season spanning from July to October in Acre and from June to August in Rondonia Mean annual rainfall is approximately 2000 mm and mean temperatures are 22 26 C Soils in Acre are Oxisols (Latosolo Amarelo Vermelho Distroficos) and in Rondonia are Oxisols (Latisolos) Alfisols (Terra Roxa) and Ultisols (Podzolicos) The population of Acre is 426 000 and that of Rondonia is 1 350 000

Reported cattle herd size in 1990 was 40 000 in Acre and 1 700 000 in Rondonia Reported crop production in Acre for 1993 was 32 000 t of rice 36 000 t of maize 14 000 t of beans 20 000 t of cassava and 12 000 t of oranges Rondonia produced a reported 275 000 t of rice 390 000 t of maize 93 000 t of beans 650 000 t of cassava 166 000 t of coffee and 26 000 t of banana Forest products for Acre were rubber (12 000 t) Brazil nuts (*Bertholletia excelsa* locally *castanha* 18 000 t) and wood (300 000 m^3)

Pedro Peixoto Acre and Theobroma Rondonia The Pedro Peixoto colonization site covers 370 000 ha divided into 3700 parcels distributed to 3200 families Lots are located at distances of 50 to 100 km from the state capital of Rio Branco Theobroma covers 300 000 ha divided into 3000 parcels (reportedly) distributed to 3000 families The project area is located some 350 km from the state capital of Porto Velho (Marcus Vinicius personal communication)

METHODS Farmer settler Interviews

A goal of the ASB project is to characterize each site in a way that data can be synthesized and compared across sites Coordinated by ICRAF researchers met in Porto Velho in late 1993 to develop and pre test a survey questionnaire that would be applicable across sites This prototype questionnaire was revised for use and application in Acre and Rondonia in mid 1994 by researchers from CIAT and IFPRI in order to ensure appropriateness to local conditions to ensure ease of use in the field and to facilitate data coding Booklets to code data from each questionnaire were developed Open ended questions were included which were coded after the range of responses were reviewed Questionnare and the data coding booklets were finalized after daily modifications and group discussions in an initial week of fieldwork

Fieldwork took place in late August and early September 1994 as settlers were burning their fields Participants represented CIAT IFPRI EMBRAPA (CPAF Acre and CPAF Rondonia) with interviewers from the Grupo de Pesquisa e Extensao em Sistemas Agroflorestais do Acre (PESACRE) a non government organization contracted by EMBRAPA

A team of some 15 interviewers was assembled and interviewers worked individually (native speakers of Portuguese) or in pairs (where the additional person was not a Portuguese native speaker) Pedro Peixoto and Theobroma were divided into areas which are relatively accessible or inaccessible during the rainy season The group selected and worked in different areas in each site each day and farmers were selected at random in the field by distributing interviewers at considerable distances from one another and then if appropriate by using an every third parcel approach Eighty one farmers in Pedro Peixoto and 74 farmers in Theobroma were interviewed with either or both male and female heads of household included

Completed questionnaires were reviewed and data passed to codebooks each evening There were considerable difficulties *in obtaining complete interviews due to inexperience* of some of the contracted interviewers The group moved to Theobroma after farmer interviews in Pedro Peixoto and lastly worked together in Porto Velho to make sure that data coding was as complete and readible as possible

Copies of completed questionnaires were left with EMBRAPA for their data analysis and publication CIAT also retained copies of the interviews and has reviewed and cross checked data revised the coding system as needed set up data archives and entered and tabulated data This paper presents and discusses descriptive findings (simple frequencies and means) from this tablulated data

GIS and Remote Sensing

The CIAT team assembled available maps and secondary data from various sources and digitized data in order to present simple overlays of for example project roads and parcels by access in the wet season and roads and parcels by soil type Satellite images of the site are being sought in order to analyse rates of deforestation over time and as functions of distances from roads (both primary and secondary) and time of road construction An overlay of the parcellary or cadastral maps on the images is allowing for analysis of deforestation by parcel access parcel tenure and other variables

RESULTS Farmer Survey

Heads of household in earlier settled Theobroma were born in the Northeast (47%) South (38%) and Center West (12%) raised in the Southeast (48%) Northeast (22%) and South (20%) and prior to arrival in Theobroma lived in the Southeast (40%) South (31%) and Northeast (16%) The data indicates high geographical mobility a) away from the Northeast b) to and then from the Southeast c) and from the South Few Theobroma settlers were born raised or lived previously in the North Pedro Peixoto settlers had a different pattern of movement and settlement Almost half were born (45%) raised (41%) and last lived (50%) in the North Approximately a third were born and raised in Acre itself and a third although not born or raised there lived in Rondonia piror to settlement in Pedro Peixoto Other main points of origin for Pedro Peixoto settlers were the South and the Northeast (Table 1) Settlers left previous places of residence largely in search of land (52% in Pedro Peixoto and 58% in Theobroma) and a better life (Table 2)

Table 1 Origins of heads of household (% of respondents) Pedro Peixoto Acre (n = 81) & Theobroma Rondonia (n = 74) Brazil 1994

	Pedro Peixoto			Theobroma		
	Born	Raised	Last	Born	Raised	Last
North (Amazonia)	**45**	**41**	**50**	3	4	1
Rondonia	0	3	34	3	4	1
Acre	**35**	**35**	**10**	0	0	0
Other	10	3	6	0	0	0
Northeast	**25**	12	14	**47**	22	16
Southeast	0	20	12	0	**48**	**40**
South	**27**	**22**	**20**	**38**	20	31
Center West	3	4	4	12	5	12

Table 2 Reported reasons (% of respondents) for leaving previous residence Pedro Peixoto (n = 60) and Theobroma (n = 67)

Reasons for leaving	Pedro Peixoto	Theobroma
No land	52	58
Search for better life	18	25
Work on rubber plantation	10	
Others	20	17

Although Theobroma was initiated as a colonization project earlier than Pedro Peixoto settlers had lived in the former a mean six years and in the latter a mean eight years possibly indicating either arrival of a second generation of settlers in Theobroma or inclusion in Pedro Peixoto of early spontaneous settlers who remained in the project area For Pedro Peixoto almost a third arrived prior to 1975 and two thirds arrived in the 1980s For Theobroma arrival was mainly in the 1970s (36%) and 1980s (58% Table 3)

Mean sizes of respondents parcels were 88 ha in Pedro Peixoto and 76 ha in Theobroma For Pedro Peixoto and for 1993 94 a mean 69% was still forested 20% was in pasture 6% in fallow and 4 % in annual crops Theobroma was characterized by more cleared land (46%) more pasture (26%) and more perennial crops (5% Table 4) Because interviews were conducted after field burning for 1994 95 changes in land use from 1993 94 to 1994 95 could be calculated additional forest clearing in late 1994 meant that forested portions of the settlers parcels decreased from 69% to 66% in Pedro Peixoto and from 54% to 50% in Theobroma Overall some 60% of the land in the two colonies remains forested with more than half of the cleared area converted to pasture Only 7% of settlers lands were in fallow (Table 4)

Table 3 Year of arrival (% of respondents) in Pedro Peixoto (n = 81) and Theobroma (n = 74)

Year	Pedro Peixoto	Theobroma
1990 94	3	3
1985 89	**40**	**24**
1980 84	**23**	**34**
1975 79	5	**21**
1970 74	13	15
< 1970	16	3
Total	100	100
Mean years at site	**8**	**6**

Table 4 Land use (mean areas) Pedro Peixoto Acre (n = 81) & Theobroma Rondonia (n = 74) 1993/94 & 1994/95

	Pedro Peixoto				Theobroma				
	93/94		94/95	Dif	93/94		94/95	Dif	
	ha	%	%	%	ha	%	%	%	Total
Forest	61	**69**	66	5	4 1	**54**	50	7	**61**
Cleared	27	**31**	34	+11	3 5	**46**	50	+8	**39**
Pasture	**17**	**20**	**25**	**+30**	**2**	**26**	**29**	**+10**	**23**
Fallow	5	6	2	60	**0**	8	4	50	7
Annual crops	4	4	7	+50	6	7	9	+40	6
Perennials	1	1	0		5 4	5	8	+50	3
TOTAL	**88**	100	100		**7** **6**	100	100		100

Settlers cleared a mean of slightly more than one ha of primary forest per year at both sites Two thirds of Pedro Peixoto farmers cleared primary forest every other year while most Theobroma farmers cleared every other year (46%) or every three years (25% Table 5) Farmers in Pedro Peixoto needed 23 days/ha to clear primary forest and 16 days/ha to clear fallowed land Theobroma farmers spent less time clearing land but needed the same amount of labor to clear forest and fallow (14 days/ha Table 6) Reasons for differences between sites were not apparent Farmers used chainsaws axes and machetes to clear primary forest and axes and machetes to clear secondary forest Labor was mainly family followed by hired labor often for chainsaw operation (Table 6)

Table 5 Respondents reported frequency of forest clearing (% of respondents) & mean area of forest cleared per year (ha) Pedro Peixoto and Theobroma

	Pedro Peixoto	Theobroma
Does not clear forest	4	2
Frecuency of clearing	9	13
Every year	**66**	**46**
Every two years	17	**25**
Every three years	4	14
> 3 years		
Total	100	100
Mean area cleared/year (ha)	**1 2**	**1 1**

Table 6 Respondents reported labor use (type and days/ha) for cutting & slashing forest and fallow prior to burning (days/ha) Pedro Peixoto and Theobroma

	Pedro Peixoto		Theobroma	
	Forest	Fallow	Forest	Fallow
Labor use (days/ha)	22 6	16 4	13 5	13 6
Labor type (% respondents)				
Family	72	81	92	85
Hired	30	12	56	25
Exchange	8	2	10	4
Use chainsaw	90	1	89	6

Burning of slash followed cutting and a period of drying Most farmers thought that the function of burning was to make space for the crops and only a few at each site mentioned that ash improved soil fertility or that fire decreased the incidence of weeds and other pests (Table 7) This result highlights differences between such settlers and traditional slash and burn agriculturalists who universally perceive burning in terms of nutrient management and pest control

Farmers (92% in Pedro Peixoto and 70% in Theobroma) planted rice in the first year of cultivation of what was primary forest and cultivated maize cassava (in Pedro Peixoto) and pasture in the second year Rice the most important crop for both consumption and sales of surpluses was not grown in the second or subsequent years of plot use (Table 8)

Table 7 Respondents reported reasons (% of respondents) for burning slash Pedro Peixoto and Theobroma

	Pedro Peixoto	Theobroma
Clear land/make space	81	79
Ash/fire improves soil fertility	11	10
Remove weeds/pests	11	6

Table 8 Respondents reported land use first & second years (% respondents) after clearing Pedro Peixoto (n = 70) & Theobroma (n = 67)

	Pedro Peixoto		Theobroma	
	1st	2nd	1st	2nd
Rice/rice + maize(beans)	**92**	0	**70**	0
Maize	0	**42**	0	**44**
Cassava	0	**26**	0	0
Pasture	1	**17**	13	**25**
Fallow	0	8	0	8
Other	7	7	17	23
Total	100	100	100	100

Farmers reported their 1993 and their normal low and high yields for rice maize and beans in terms of ratios of yield to seed sown Yields in 1993 were somewhat below average with normal yields at the two sites being about 70 75 1 for rice 95 1 for maize and 27 1 for beans (Table 9) Mean reported yields at both sites did not differ Farmers *reported sowing from seven to 60* kg of rice seed per ha at both sites with a mean of about 21 kg/ha Farmers normal rice yields would then be in the 1 5 to 1 6 t/ha range which would appear to be a reasonable estimate given local conditions and farmers management practices

Most farmers at the two sites reported problems (defined as factors which led to decreased yields) with rice and beans Stink bug stemborer and birds in Pedro Peixoto and birds and storage weevils in Theobroma were problems of rice (Table 10) Web blight (*Thanathephorus cucumeris*) and beetles (*Diabrotica* spp) were the major problems of beans at both sites Few farmers reported problems with maize although problems mentioned included birds wild animals and spittle bug (*Deois flavopicta*)

Table 9 Respondents reported mean normal low and high crop yields (ratio of production to seed sown) Pedro Peixoto and Theobroma

	Pedro Peixoto				Theobroma			
Crop	1993	Normal	Low	High	1993	Normal	Low	High
Rice	63	70	34	103	69	75	42	96
Maize	88	94	56	118	76	96	59	154
Beans	19	28	4	52	10	26	10	41

Farmers cultivated lands cleared from primary forest for a mean period of two (Pedro Peixoto) to 2 5 years (Theobroma) Sixty percent in Pedro Peixoto cultivated such plots for two years while Theobroma farmers used their newly cleared lands for from one to more than three years in somewhat equal proportions (Table 11) Again reasons for differences between sites were not apparent and bear further investigation Farmers reported that discontinuation of annual cropping on lands cleared from forest was due to the not mutually exclusive reasons of lower productivity weeds especially *Imperata* sp (locally *sape*) and insects and diseases (Table 12)

After food crops two thirds of Pedro Peixoto farmers and nearly half of Theobroma farmers converted their lands to pasture About a third in both areas left some land in fallow (although much of such land may also be used as unimproved pasture) Theobroma (20%) but not Pedro Peixoto farmers also converted some land from annual to perennial crop use (Table 13) Farmers at both sites normally left any fields which they fallowed for a mean 2 5 years although they thought that 3 0 3 5 years of fallow would be ideal Rice followed by maize and beans were the main crops planted in the re opened fallows (Table 14)

Table 10 Reported crop problems (% of respondents) Pedro Peixoto (n = 71) & Theobroma (n = 72)

Problem	Local Scientific names	Pedro Peixoto	Theobroma
	RICE		
Has problem		78	65
Stink bug	*Percevejo Tibraca* spp *Oebalus* spp	45	5
Birds	*Pasarim/Grauna*	14	34
Stemborer	*Panicula branca Diatrea* spp	17	5
Diseases	Symptoms referred to as *quema*	7	2
Storage weevils	*Gorgulho*	6	15
Miscellaneous		31	28
	MAIZE		
Has problem		41	28
Birds	*Pasarim*	5	8
Wild animals		0	5
Spittle bug	*Cigarinha Deois flavopicta*	5	2
Storage weevils	*Gorgulho*	14	5
Miscellaneous		23	18
	BEANS		
Has Problem		78	96
Web blight	*Mela Thanathephorus cucumeris*	58	58
Chrysomelides	*Vaquinha Diabrotica* spp	30	40
Miscellaneous		29	28

Table 11 Respondents reported normal years of cultivation of lands cleared from forest (% of respondents) Pedro Peixoto & Theobroma

Years cultivated	Pedro Peixoto	Theobroma
1	13	**26**
2	**60**	**24**
3	16	**31**
>3	11	**19**
Total	100	100
Mean years	**2 1**	**2 5**

Table 12 Respondents reported reasons for discontinuation of annual cropping in what were newly cleared lands (% of respondents) Pedro Peixoto & Theobroma

Reason	Pedro Peixoto	Theobroma
Lower productivity	36	**68**
Weeds	**51**	34
Weeds *sapé*	**43**	5
Diseases & pests	25	12
Other	31	40

Table 13 Respondents reported general or normal use of lands after annual cropping (% of respondents) Pedro Peixoto (n = 70) & Theobroma (n = 67)

Land use	Pedro Peixoto	Theobroma
Pasture	**64**	**44**
Fallow	**36**	**36**
Perennials	0	20
Total	100	100

Table 14 Respondents reported use of fallow (years & % of respondents) Pedro Peixoto and Theobroma

	Pedro Peixoto	Theobroma
Years of last fallow	2 4	2 7
Years ideally fallowed	3 4	3 1
Years normally fallowed	2 4	2 4
Crop planted after fallow (%)		
Rice	**62**	**72**
Maize	**23**	**13**
Beans	12	8
Cassava	3	0
Pasture	0	2
Other	0	5

For perennial crops 35% of Pedro Peixoto farmers reported problems of low prices or poor markets 29% reported no problems and 40% had not grown perennials In Theobroma only 20% *had not grown perennials 43% reported production problems* (i e *insects and* diseases) and 45% reported having had no problems (Table 15)

Most settlers (91% in Pedro Peixoto and 81% in Theobroma) had cattle Herd size was a mean 18 head (with 6 giving milk) in Pedro Peixoto and 26 (4 giving milk) in Theobroma (Table 16) Milk production ranged from a mean two to three liters per head in the dry season and four to five liters in the wet season Settlers reported stocking 2 2 head per ha in Pedro Peixoto and 1 6 head per ha in Theobroma with roughly equal numbers of respondents at both sites reporting stocking a) less than one b) one to two and c) more than two head per ha (Table 17)

Table 15 Respondents reported problems (% of respondents) with perennial crops Pedro Peixoto (n = 17) and Theobroma (n = 49)

Problem	Pedro Peixoto	Theobroma
Production problems	6	**43**
Low prices/poor markets	**35**	10
Lack of transport	18	0
Too much labor required	3	1
Fire during burning season	12	2
No problem	**29**	**45**
Has not grown perennials	**40**	**20**

Table 16 Respondents reported livestock holdings (head) Pedro Peixoto and Theobroma

	Pedro Peixoto	Theobroma
Percent of settlers with cattle	91	81
Number of cattle		
Maximum number in last year *	18	26
Number sold in past year	4	2
Current number	23	30
Milk		
Mean number giving milk (head)	6	4
Mean liters/head/day dry season	2	3
Mean liters/head/day wet season	4	5

Difference in maximum number last year and current number reflects cattle born deaths and purchases

Table 17 Current number of anımals per ha (% respondents) Pedro Peıxoto and Theobroma

Anımals per ha	Pedro Peıxoto	Theobroma
< 1	33	37
1 2	38	37
> 2	29	26

The predomınant pasture specıes used at both sıtes were *Brachıarıa brızanta B decumbens* and *B humıdıcola* Some Pedro Peıxoto farmers also had *Puerarıa phaseoloıdes* or mıxes of *P phaseoloıdes* and brachıarıa Theobroma settlers also had pastures of *Panıcum maxımum* (Table 18) In terms of pasture management a mean 70 75% of farmers burned fıelds yearly and 70% of farmers at both sıtes rotated catttle to dıfferent pastures at a mean of every 2 0 2 5 months (Table 19)

Table 18 Respondents reported types and areas (% & ha) of pasture Pedro Peıxoto & Theobroma

	Pedro Peıxoto			Theobroma		
	% of respondents	mean area (ha)	% of area	% of respondents	mean area (ha)	% of area
Brachıarıa brızanta	80	12	57	78	15	51
Brachıarıa decumbens	60	7	24	36	9	13
Brachıarıa humıdıcola	11	3	2	32	5	5
Puerarıa phaseoloıdes	7	4	1			
Panıcum maxımum				12	7	3
P phaseoloıdes + B decumbens	7	22	10			
Other mıxtures	4	7	2	8	20	7
Natıve pasture	7	8	3			
Other	12	2	1	37	11	21

Table 19 Pasture management practices (% of respondents and frecuency over time) Pedro Peixoto & Theobroma

	Pedro Peixoto	Theobroma
Use fire for regeneration (%)	75	71
Frequency of fire use (years)	1 3	1 1
Rotate cattle to different pastures (%)	70	70
Frequency of rotation (months)	2 6	2 1

Table 20 Respondents (%) use of forest products Pedro Peixoto and Theobroma

Forest Product	Pedro Peixoto	Theobroma
Brazil nut	90	36
Wood	33	50
Hunting	18	29
Palmito	5	17
Fish	6	13
Rubber	11	0
Medicinal plants	5	6
Acai (another palm)	0	6
Jatoba (a tree legume)	0	6
Other	11	4

Settlers exploited their forest lands for Brazil nut (although substantially more in Pedro Peixoto) wood hunting palm hearts (more in Theobroma) fish and rubber (Pedro Peixoto Table 20) Although an attempt was made quantities of these products were very difficult to elicit or calculate

Farmers cash income sources (Table 21) in Pedro Peixto were from sales of labor or pensions (63%) and sales of rice (50% sold a mean 2 3 t/year) maize (47% 1 8 tons) beans (41% 1 3 tons) Brazil nut (44% 1 0 tons) and cattle (26%) More farmers (57%) sold more rice (3 1 tons) in Theobroma in addition to having incomes from labor and pensions (53%) coffee (36% 3 3 tons) milk (30%) cacao (25% 1 6 tons) and cattle (22%)

Table 21 Respondents (%) sources of cash income and approximate quantities sold (tons/year) Pedro Peixoto (n = 68)* and Theobroma (n = 63)*

Source	Pedro Peixoto	Quantity	Theobroma	Quantity
Crops				
Rice	**50**	2 3	**57**	3 1
Maize	**47**	1 8	**16**	2 7
Beans	**41**	1 3	**9**	0 2
Cassava	4	1 5	0	
Farinha	7	4 1	0	
Cotton	1	0 6	9	0 4
Coffee	3	1 3	**36**	3 3
Cacao	0		**25**	1 6
Cattle (head)	**26**	23	**22**	5
Milk	7		**30**	
Poultry/pigs	9		0	
Rubber	7	1 6	0	137
Castana	**44**	1 0	6	
Wood	0		9	
Other	9		8	
Labor and pensions	**63**		**53**	
Agriculture male	11		26	
Agriculture female	3		0	
Non agr males	15		8	
Non agr female	16		1	
Pensions	19		16	

Fewer respondents provided quantities of each product

Farmers may be earning more from appreciation of land values 93% of Pedro Peixoto and 97% of Theobroma settlers perceived their land values as having risen (values were discussed in terms of equivalent numbers of cattle) at annual rates of 74% in the former and 157% in the latter Farmers reported total increases since occupying their parcels in value of about 800% in Pedro Peixoto and 950% in Theobroma with reasons for increases attributed to addition of pasture or cleared areas fencing ponds or other water sources corrals houses perennial crops and improved access (Table 22) Negative factors associated with the colonies were poor roads or access malaria and lack of health posts schools and potable water (Table 23)

Table 22 Respondents evaluation of and reasons for (% of respondents) changing land values Pedro Peixoto (n = 69) and Theobroma (n = 70)

	Pedro Peixoto	Theobroma
Reported increased value (%)	93	97
Total mean increment in cattle (%)	778	952
Mean annual increment in cattle (%)	74	157
Reasons for increase		
More pasture	60	50
Fencing	56	36
Pond/water	30	13
More cleared area	12	26
Corral	12	16
House	26	16
Access/roads	25	27
Perennial crops	12	35
School	10	5
Timber	8	1
Title	7	3
Good soils	4	5

Table 23 Respondents (% of respondents) reported negative factors associated with living in Pedro Peixoto or Theobroma

	Pedro Peixoto	Theobroma
Poor roads/access	51	27
Malaria	25	35
Lack of transport	24	9
health post	22	30
schools	14	22
potable water	10	4
electricity	4	8
credit	10	1
Other	23	21
None	4	11

GIS and Remote Sensing Results

Overlaying the Theobroma parcel map on a Brazilian soils map shows about 1400 parcels (37% of parcels) and 114 thousand ha (45% of area) of more favorable Alfisols (Podzolico Vermelho Amarelo Eutroficos) 2200 parcels (57%) and 124 thousand ha (49%) of medium quality Oxisols and Ultisols and 250 parcels (6%) and 14 thousand ha (6%) of poor Distropepts (Liticos distroficos Table 24 This mapped data will permit a follow up study to determine if there are differences in land use and in productivity relative to soil quality The same mapping of cadastral data and soils in Pedro Peixoto showed that soils throughout the site are relatively similar in terms of agricultural potential (Bell and Fujisaka forthcoming)

Parcels in Pedro Peixoto with titles and with titles pending were mapped for Pedro Peixoto (Table 25) and will be overlayed on satellite images in order to determine the role of tenure on rates of deforestation Finally a satellite image from 1991 which includes Pedro Peixoto five haciendas and other land uses and covers 357 thousand ha of which 19% of the total is deforested 20% of the colonists 270 thousand ha 29% of the haciendas 22 thousand ha and 10% of the 64 thousand ha of other were deforested (Table 26) The officially reported area of the Pedro Peixoto project of 370 thousand ha appears to include what are now haciendas and other land uses besides settlers parcels The currently farmer reported amounts of forest clearing appear to agree with the image analysis given their reported rates and the amounts shown in the 1991 image and given that analysis was unable to distinguish between relatively established secondary growth and primary forest As mentioned additional analysis is attempting to analyse deforestation as a function of distance from roads and additional images are being obtained to analyse rates in Pedro Peixoto and Theobroma over time

Table 24 Number of parcels and area (ha) by soil quality Theobroma

	Parcels		Area (ha)		Soil Type
	Number	%	ha	%	
Good	1392	37	113 524	45	Alfisols
Medium	2172	57	123 689	49	Oxisols Ultisols
Poor	241	6	14 120	6	Distropepts

Table 25 Number and area (ha) of lots with titles and with pending titles Pedro Peixoto

	Parcels		Area (ha)	
	Number	%	ha	%
With titles	1103	74	75 253	74
Title pending	379	26	26 021	26

Table 26 Satellite image analysis of Pedro Peixoto (1991)

	Forest		Deforested		Total
	Ha	%	Ha	%	Ha
Total (ha x 000)	290 3	81	66 4	19	356 7
Colonists lots	217 5	80	53 5	20	271 0
Haciendas (5)	15 5	71	6 4	29	21 8
Other	57 4	90	6 5	10	63 8

DISCUSSION

Deforestation at the farm level appears to continue at a relatively steady pace averaging somewhat more than one ha per year per family in the two colonies Settlers still had more than half of their lands in forest and for the most part can and probably will continue to slash burn and cultivate more primary forest as their currently most (economically) viable option Two main factors driving land clearing at the farm level were the need to produce food crops and incentives to convert land into pasture In terms of food production farmers consumed and sold rice and to a lesser extent beans maize and cassava (or cassava meal) Rice cultivation may drive some deforestation in that although farmers usually planted a cleared field for two or three years they could not for technical reasons sow rice other than in the first year after clearing As such a research priority of the ASB project may be to determine if and under which management alternatives could rice production be made more sustainable (acknowledging the caveat that any improvement in productivity may lead to greater economic attractiveness of the respective enterprise and thereby invite more deforestation or other forms of resource over exploitation)

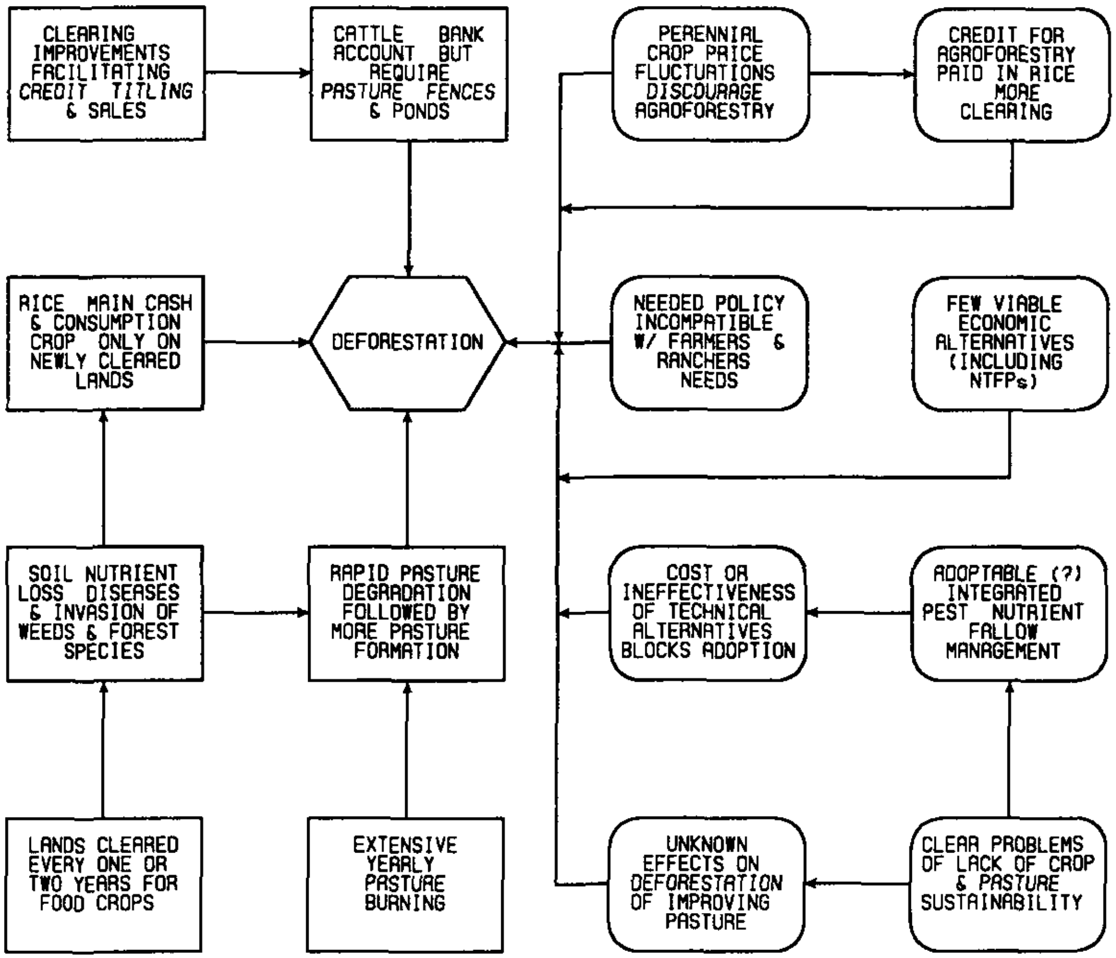
Farmers were clearly motivated to convert cleared lands into pasture because of real or at least perceived resulting increases in land values Farmers not only maintained cattle as standing bank accounts and obtained cash from sales of animals and milk but built savings by investing time and resources in fencing corrals ponds and other ranching necessities As observed throughout the two sites local ranchers and urban based specultors have purchased continuous blocks of colonists parcels to form new ranches or to expand the size of adjacent ranches and payments were reportely much higher for cleared vs forested portions of parcels Farmers pasture management practices consisted of introducing mainly *Brachiaria* spp annual pasture burning and rotation of annimals to different pastures In spite of generally low stocking rates there were substantial areas of poor and degraded pastures and pasture lands at both sites Although construction of new cheese processing plants near Theobroma may result in intensification at that site extensive and low input cattle and pasture management appear to be the current norm for both sites Whether or not improved pasture technologies are possible and would be appropriate to farmers current conditions is another researchable issue

Conversion of cleared forest land to pasture has meant that at least in the colonies studied that there was relatively little land placed in fallow with resulting secondary regrowth and forest regeneration An implication is that research on improved fallows may either result in making fallows more attractive to farmers (as is hoped) because of more rapid regeneration and better mainatenance of soil organic matter or farmers may be uninterested in improved fallows because conversion to pasture is by far the preferred land use after cultivation Interacting factors leading to deforestation at the on farm level in Pedro Peixoto and Theobroma are presented in a qualitative model (Figure 2)

Theobroma farmers practiced agroforestry in the sense that they had significant areas of perennial crops mainly coffee and cacao Pedro Peixoto settlers have had less favorable experiences regarding perennials citing poor prices and/or markets as major constraints Some Pedro Peixoto farmers had been encouraged (provided with credit) to plant *urucu* (*Bixa orellana* used to produce red dye) When the trees started to produce prices for the product fell to the point that farmers could not afford to harvest and lost their investements Currently settlers in Theobroma were being provided credit to grow *acerola* (*Malpighia punicifolia*) Although they were promised a future market for all that they produce schemes to introduce or encourage perennial crops or agroforestry remain risky

A resource that was largely not available in the systems examined is indigenous technical knowledge of the type usually associated with shifting cultivators Farmers were asked about their soil and land classification and corresponding use systems Although they distinguished soils by color and texture and called attention to lands either having a sub surface compacted layer or low waterlogged areas they did not employ such distinctions in choosing areas to clear and cultivate Farmers simply cleared land in steady sequence from the areas closest to the roads and houses and towards the rear of their parcels Although a few named plant species which indicated soil impoverishment and others which indicated fallow regeneration most farmers appeared to have little concept of use of fallows for biomass (and subesequent soil fertility) regeneration or of (as mentioned) the use of fire to release nutrients for crops use Only a few Theobroma farmers mentioned that there were medicinal plants that could be harvested from the forest

FIGURE 2 DEFORESTATION CAUSES & FARMER RESPONSES TO RESEARCH TO DECREASE RATES



CONCLUSIONS

The heartening news is that rates of deforestation in the Amazon Basin appear to be decreasing due to fewer incentives to large corportations to invest in cattle ranching a virtual end to a period of road building to open up the Amazon and to protect frontier areas and a decline in government assisted colonization programs for the rural poor Secondary forests have shown relatively high rates of regeneration both after slash and burn agriculture and after abandonment of degraded pastures and a significant proportion of deforestation for shifting cultivation is now of secondary rather than primary forest

On the other hand deforestation and/or consolidation of colonists parcels to form or expand ranches has continued with ranches now being formed less by frontier risk takers and more by urban speculators in areas where land prices have risen and where govenment can protect such investment The evidence presented suggests that deforestation on colonists parcels continues at an apparent steady pace driven by food production needs and by incentives similar to those now pushing formation of larger ranches

To some extent the characterization data suggest the need for on farm research to develop alternatives to slash and burn agriculture Such research already underway or planned needs to examine the possibility of making rice production more sustainable (and thereby hopefully reducing demand for newly cleared forest) improving (i e intensifying to the degree appropriate) pasture and cattle management introducing or encouraging more perennial cropping and agroforestry and improving fallows At the same time and equally or more importantly this analysis recognizes the importance to deforestation of national policies regarding road construction credit tax incentives frontier settlement land tenure and the rural poor Development of alternatives will need to include susbstantial attention to policies and future policy options

CHAPTER II

PROJECTS TL 01 and TL-03 PROTOTYPE SUSTAINABLE CROPPING SYSTEMS FOR THE LLANOS AND DYNAMICS OF LAND USE

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A INTRODUCTION JUSTIFICATION

The purpose of this project is to generate technologies that allow lasting increases in the efficiency of resource use and that control soil and water degradation

The Colombian Llanos have traditionally been dedicated to extensive cattle ranching but this is changing through the introduction of annual crops and new cattle based systems Remote sensing and ground truthing studies indicate increasing signs of environmental degradation such as erosion and loss of native species as a result of the more intense use of native vegetation by cattle as well as other non suitable forms of land preparation and management

This project aims to reconcile more intensive agricultural production with conservation and enhancement of the natural resources for the diverse conditions found throughout the Colombian Llanos

The project includes amongst other aspects long term trials aiming to contrast existing and new technologies generated by the Tropical Lowlands Program (TLP) for the South American savannas

B PROBLEM SOLVING STRATEGY AND EXPECTED OUTPUTS

The following studies are being carried out and illustrate the project s strategy

Traditionally native vegetation for grazing in the savannas is burnt in order to have fresh and tender new regrowth to feed cattle With the possibility of growing crops it is also necessary to dispose of either native vegetation and/or crops/weeds residues Burning is a cheap way for doing it and our work has shown positive effects of burning residues on crop yields Unfortunately burning is not ecologically sound and for obvious reasons the Program has started research since early 1994 in order to look for economically feasible and environmentally friendly practices to dispose of such residues without burning or at least to reduce the frequency of its use

In the last few years several improved pasture species grasses and legumes adapted to acid soils have been successful in systems with rice either for their establishment or their recuperation New crops have been making their way into the acid savannas One of the successful crops has been acid soil tolerant maize developed by CIMMYT and CORPOICA Before the release of the first variety for savannas and through collaboration between CIMMYT and the TLP it was decided to evaluate from early 1994 maize pastures systems also to have another alternative to the not so much desirable monocrop

The mew maize variety cv Sikuani 1 is adapted to soils with up to 60% Al saturation This means liming the original soil with 1 1 5 t/ha to lower Al saturation whereas fertilization requirements are similar to those of rainfed rice This amount of lime represents a major qualitative change in cropping systems and for the Llanos at least it is representative of relatively high input systems in which the soil is partially modified to suit a more demanding crop It is further hypothesized that the residual value of lime and fertilizers allow the introduction of relatively more demanding forage germplasm such as *Panicum maximum* cv Vencedor selected in Brazil for the better endowed Cerrado soils

In order to cope with site specificity and looking for both extrapolation of results from trials and collection of data in representative areas the following cross sectional studies are being carried out

Farms located in contrasting land systems in the Colombian Llanos differ significantly in the use of resources Some of these differences are associated with variation 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 systems are being monitored in the two main land systems of the Colombian Llanos #201 with 424 000 ha of flat land virtually identical to #202 with 1 447 800 ha and #203 with 1 200 000 ha of rolling slope topography

Whole farm inputs and outputs are being monitored from the beginning of this 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 physic chemical characterization with the objective of relating present use to soil parameters An attempt at characterizing soil biological activity is being made in cooperation with the Universidad Tecnológica de los Llanos (UT) Similarly in those areas under native vegetation or introduced pastures surveys are being made for botanical composition and stocking density and grazing also with the cooperation of Universidad Tecnológica de los Llanos

A detailed GIS coverage is being developed in the Colombian Llanos study area (between Puerto Lopez and Puerto Gaitan Department of Meta) This is to help the Lowland Tropics team to classify their experimental sites to extrapolate from them and to assist in monitoring the change in land use and the adoption of new technologies as they are developed

The Augustine Codazzi 1 100 000 scale map of soils for the area has been digitized A user interface has been developed for this GIS coverage It includes data on soil characteristics drainage topography etc in 11 different data coverages The 1 25 000 topographic maps are in the process of being digitized The topography has been completed Digitizing of the drainage lines is at present in process their direction and the start and endpoints of each of the drainage arcs being noted This will be used in conjunction with a Laplacian spline algorithm to calculate the digital elevation model for the whole of the study area The model is needed to accurately calculate slopes and runoff for applying catchment management and erosion control models Digitizing topography at this scale is very labor intensive In fact this project has taken up over 3 man years of work to date

Satellite images for various previous years have been obtained and at present the 1989 Landsat TM image is being analyzed The analysis being conducted is known as an unsupervised classification Since ground truth for 1989 is unavailable the classification algorithms of the satellite image analysis software are allowed to produce the best possible resolution of classification of the image without the type of ground cover it is denoting in its classification actually being known This is now being used to produce a stratified sampling which will allow field work and sampling of actual ground truth (i e recording the actual land use on the ground in individual fields regeoreferenced to the satellite image) This will be at the end of January 1995 A Landsat TM image has been commissioned which will then be directly related to the ground truth of the area This will allow construction of a supervised classification in which the actual land use is known

With the supervised classification and the topographical images from the digital elevation model that classification can then be transposed back in time to the previous images and trends in land use obtained Series of air photographs dating from the 1940s at roughly 5 year intervals are also available Having obtained the supervised land use classification from the most recent satellite image certain study areas will be selected for interpretation from the air photographs and a series of land use change images running back over the last 40 years will be constructed These will be used as base data for producing models of land use change in the area 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 vegetation surveys 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 and temporal simulation of alternative land uses and to evaluate their impact on the region

For an analysis of land use dynamics in the Llanos see report for Project TA 02

See also Subprojects T 01 2 Adoption of ley farming systems in the Colombian Llanos and T 03 1/2 Vegetation and ecology of the serranía native pastures of the Eastern Plains of Colombia Llanos and Native pasture management

For the purpose of this report and in order to illustrate the strategy two on going long term contrasting trials started in 1989 will be discussed here

These two trials represent contrasting systems for which CIAT in collaboration with other international and national institutions has been developing both the germplasm (crop and pastures) and the technology for their management

One of them continuous upland rice monocropping was established since early 1989 with the purpose of following closely what could be the most obvious type of adoption of the then promising germplasm now released The fear then was that of further degradation of the already very acid infertile and erosion/compaction prone Oxisols if utilized under continuous monocropping

The initial hypothesis was that yield would decline over time and the soil resource would degrade after a few years of continuous cropping

The trial has been closely monitored and attempts were made to optimize soil chemical physical and microbiological changes as well as weed incidence with the aim of maintaining yields without decline i e trying to make it sustainable if at all possible

In contrast an experiment in which rice and grass legume pastures are sown together at the same time and sharing the same field was also established early 1989 This was one of CIAT s technological alternatives to the potential risk of monocropping and also an alternative to traditional ranching The hypothesis was that it would be possible to produce rice economically while establishing improved pastures which in turn would benefit from the residual fertility left by the rice crop With this monocropping would be avoided and vigorous pastures would cover the soil for a few years until a pasture recuperation was needed through another rice crop Animal productivity was expected to be enhanced as well as preservation of the resource base

Both trials above have been followed with periodical nutrient balance sheets These include the nutrient partitioning to the different parts of the system i e in the soil (before and after each cropping season) added fertilizer nutrients uptake by plants (crops grasses legumes weeds) as well as percentage taken out with produce (eg rice grain) nutrients fixed in roots or lost/not found

Additionally soil physical measurements in the second trial above are also being useful to monitor compaction of grazed vs non grazed pastures These pastures also yield valuable information on rates of forage biomass production

Records on the use of machinery are available This will allow us to draw balances on the use of fossil energy

C RESULTS AND DISCUSSION

a) Continuous upland rice monocropping

In the continuous rice monocrop experiment there was a continuous linear yield decline for Oryzica Sabana 6 at a rate of nearly 400 kg/ha/yr ($r^2 = 0\ 96$) over the period 1989 to 1992 Despite fertilizer inputs being adjusted yearly based on soil tests to maintain appropriate nutrient levels and balances yields declined from 3 8 to 2 6 t/ha In 1993 with improved agronomic practices yields picked up by about 700 kg/ha Since weeds incidence was one of the most clear obstacles to have a stable production the use of herbicides was included in 1994 Unfortunately their efficiency in the savanna Oxisols is not nearly as good as it is in other rice growing areas including the Piedmont of the Llanos This will probably require site and crop specific research on weed management which should be carried out by local NARS and others See Subproject T 01 1 Weed population ecology within prototype sustainable cropping systems for the Colombian Llanos

Added to this and from the soil physics point of view several measurements have been carried along with the trial to document changes induced with the practice of continuous rice cropping

Plant roots elongate and enlarge in diameter if the pressure inside new cells is sufficient to overcome external resistance caused by surrounding soil matrix Some researchers have demonstrated that the maximum longitudinal root growth pressures of several crops range from 9 to 15 bars (1 bar $\approx$ 1 kg/cm^2) and that roots (*Raphamis sativus* L) cease to enlarge (diameter) when subjected to radial constraints of about 8 5 bar Roosell and Goss (1974) showed that 0 2 bar pressure applied to a glass bead system reduced the elongation of barley root by 50% and that 0 5 bar reduced the rate by 80% If a soil is easily deformable roots penetrate it and grow until some factor different from mechanical impedance stops elongation rate In most cases roots grow partly through existing pore spaces and partly by moving aside soil particles

Most of the penetrability values found in Matazul (Figure 1) are higher than those generally reported as limiting values (9 15 bar) specially at depths larger than 7 5 cm no matter the tillage (disk harrow mould board ploughing) treatments It is therefore likely that mechanical impedance is negatively influencing rice yields

Figure 1 also shows that the savanna average resistance values are closer together or have a lower range than those obtained by tillage treatments They vary from 12 bar (2 5 cm depth) to 22 bar (32 5 cm depth) approximately while in the disk harrowing treatment they vary from 7 (2 5 cm) to 24 bar (32 5 cm) and in mould board ploughing treatment from 8 (2 5 cm) to 25 bar (32 5 cm) These results suggest that the control (savanna treatment) exhibits better pore continuity

Another aspect shown in Figure 1 is that all treatments including the control present similar values at 22 5 cm depth showing that there is presumably a compacted layer or a change from soil to subsoil which could affect soil processes and be determinant to yields

It is clear from Figure 1 that tillage looses the soil from 0 to 22 5 cm depth but compacts it from 22 5 downwards and that mould board ploughing increases compaction in depth

The statistical analysis of the data (Table 1) shows that there are significant (P<0 05) differences in the values of penetrability when treatments are compared at 2 5 7 5 cm depth Native savanna presents the highest values which means that is more compacted In the 7 5 15 0 cm and 15 0 22 5 cm depth the analysis shows more similar values and less difference between treatments but still savanna has significantly higher values at 7 5 15 0 cm At 22 5 32 5 cm depth mould board ploughing treatment shows significantly higher values than savanna hence causing deep soil compaction

Table 1 Average soil penetrability values in the sixth year of continuous upland rice monocropping in Matazul Llanos of Colombia 1994

Treatment	Soil depth (cm)			
	2 5 7 5	7 5 15 0	15 0 22 5	22 5 32 5
	Penetrability kg/cm²			
Savanna	13 9 a[1/]	16 2 a	17 7 a	19 7 b
Mould board plough/93	10 8 b	14 7 ab	17 2 a	22 7 a
Disk harrow/93	9 3 b	14 5 b	17 5 a	21 1 b

1/ Data in the same column followed by the same letter do not differ significantly (P<0 05)

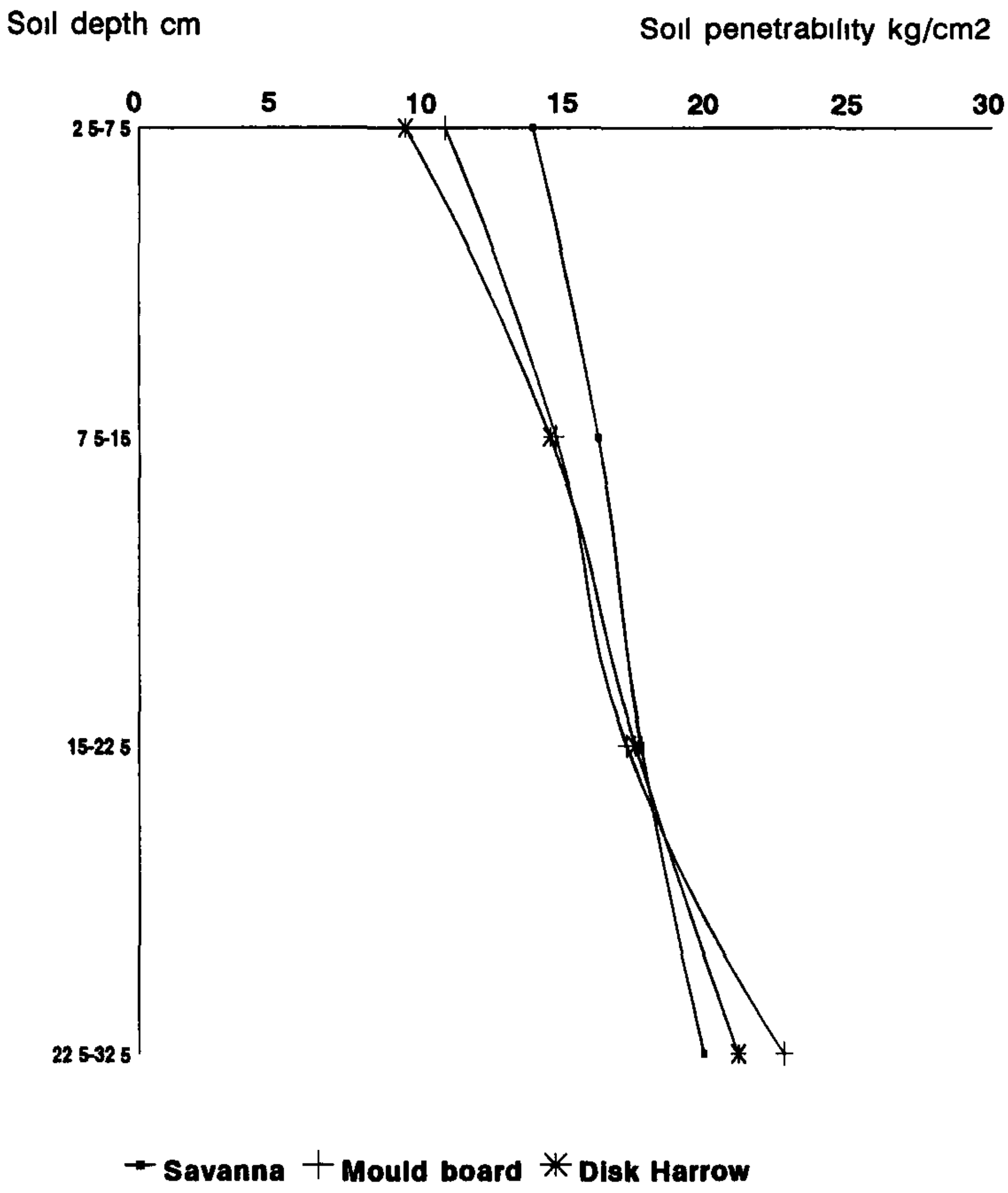

Figure 1 Average soil penetrability values in the sixth year of continuous upland rice monocropping in Matazul, Llanos of Colombia, 1994

The result of the above described phenomena was drastically reduced yields in the 1994 season going in all treatments without statistical differences between 1 6 and 1 9 t/ha the lowest ever in the six years of the trial (the lowest was 2 6 t/ha in 1992) It is obvious that weeds can be managed but a continuing process of soil physical degradation is something that poses the question on how sustainable upland rice monocropping can be Nevertheless deep chisel could break compacted layers below 20 cm and increase porosity again A question for the future is if the yearly use of tillage breaking the soil particles cemented by sesquioxides in Oxisols will push the soil capacity to reaggregate therefore making the soil eventually less structured or permanently packed

Promoting soil microbial activity and increasing soil organic matter (SOM) e g via green manures cover crops etc could help to balance the effect of tillage and continuous rice cropping but the present trial is not designed to address these issues (see nevertheless Project T 02 Culticore)

Microbial biomass N was considerably lower for the rice monocrop while microbial biomass C did not vary very much when compared to rice pastures or native savanna (see Projects T 02 TC 02) Consequently the microbial C/N ratio was more than 1 5 times as wide under continuous rice as under any other treatment and the contribution of microbial N to total organic N content was also low Residual N fertilizer did not compensate for the high C/N ratio and probably the microbial population actually competed with the crop for N

Microbial biomass P was also lower for rice than it was for rice pastures and microbial C/P ratios were at very high values suggesting also a possible microbial competition with the crop for P fertilizer Rice alone also showed a lower soil C mineralization rate than rice pastures indicating lower activity or lower energy use efficiency of the microbial population in continuous rice This is probably due to a lower organic matter input since a large part of the rice plant is removed from the field

Projects T 02 and TC 02 also indicate that the nutrient cycling pathway in continuous rice can supply much less nutrients (especially N) than in rice pastures This suggests less and poorer young organic matter in rice monocrop

In summary continuous rice yields are decreasing probably due to the following factors loss of soil physical properties and decreased microbial activity further compounded by other secondary reasons such as weed incidence

Sustainability of monocropping in a classical way in savanna Oxisols appears quite compromised after its 6th year but there is a need to continue research on the processes underlying degradation in monocropped soils

b) Rice pasture systems

In the same site a long term large (9 ha) rice (Line 3) grass/legume pastures experiment was successfully established as a prototype agropastoral system Rice yields in 1989 for either rice alone or rice pasture associations were on average 2 t/ha without statistical differences and with excellent pastures establishment Ever since the pastures were grazed with high animal weight gains in the first two years e g 755 g/animal/day on average at the beginning of the dry season 1990 1991 and a decline to lower levels in the rainy season of 1992 e g 540 g/animal/day more characteristic of traditionally established but very well managed pastures on medium textured Oxisols

By October 1992 the legumes had almost disappeared (2 5 to 3 1% of the total DM/ha) and in 1993 it was decided to split in half the 1 ha plots and keep grazing one half as long term control while recuperating the other half by planting rice and legumes and letting the grass to regrow from soil seed reserves Rice yields were between 2 5 and almost 4 t/ha (Table 2) and reestablished grass legume pastures were obtained Grazing is again taking place in these plots

Table 2 Yield of an experimental line and a released variety of upland rice (kg/ha) in rotation with different types of pastures and undersown with *Brachiaria dictyoneura* (Bd) *Arachis pintoi* (Ap) *Centrosema acutifolium* (Ca) and *Stylosanthes capitata* (Sc) Matazul Llanos of Colombia August 1993

Preceding pasture[1/]	Line 3	Oryzica Sabana 6
Ag/Sc (early seedbed prep)[2/]	3671	3926
Ag/Sc (late seedbed prep)	2987	3276
Bd/Ca (early)	2853	3390
Native savanna (early)	3143	2568
Bd (early)	2511	2758
Means	**3033**	**3184**
se	**161**	

1/ Sown pastures were 4 years old and had been initially established undersown to rice (Line 3)

2/ Early = December 92 (early dry season) Late = April 93 (beginning of wet season) Planting time = May/June 93

In these newly recuperated pastures fertilizer was added only to rice in 1989 and in 1993 for the recuperated part whereas in the rice monocrop there have been yearly additions Nutrient input/output sheets are being computed in this and in the previous experiment By the end of 1992 before reclamation in the rice pastures plots soil nutrient levels were almost down to those of the original native savanna without any further depletion or imbalance Grazing was continued in 1993 1994 in the non recuperated pastures and started in the recuperated treatments Table 3 shows the results for the current year In the recuperated pastures animal weight gains have in general been superior to those in the non recuperated pastures despite some problems in the reestablishment of the *Brachiaria dictyoneura* This grass had some regrowth due to abnormal rains during the dry season after land preparation for rice therefore there was need for a second pass of machinery to suppress its growth before establishing the rice and this deplenished soil seed reserves leading to a lower than expected population later on Thus *B dictyoneura* has proved to be less resilient than anticipated based on previous experience with *B humidicola* This is an area that still requires applied research by NARs and probably deserves some fundamental research on seed and plant population dynamics

Table 3 Animal weight gains in *Brachiaria dictyoneura* pastures renovated with rice and with and without legumes and compared to non renovated pastures in Matazul Llanos of Colombia 1993 1994

Period	Grazing days		Stocking rate (Au/ha)			Weight gains (g/animal/day)			A g
	T /T	T	T	T	T	T	T	T	
O t 12 N 30/93	49	34	2 01	1 43	0 85	578b[2/]	212c[2/]	1213a[2/]	526a[3/]
Ap 6 J 9/94	64	74	1 53	1 50	2 35	845a	396b	569b	603a
J 9 Ag 18/94	70	70	1 88	1 54	2 65	792a	119b	248b	386b
T t l	183	168							
W ght d verag			1 79	1 50	2 17				
A rag						738a	101c	676b	505

1/ T_1 = renovated *B dictyoneura* + *C acutifolium* + *A pintoi*
T_2 = pure non renovated *B dictyoneura* (long term control)
T_3 = pure renovated *B dictyoneura*
2/ Different letters in the same line differ significantly ($P<0.05$)
3/ Different letters in the same column differ significantly ($P<0.05$)

As with the rice monocrop trial soil physical properties have also been monitored

The penetrability values of the soil tilled for pastures renovation with rice are significantly lower ($P<0.05$) than those of native savanna and non renovated pastures in the range 3 5 17 5 cm depth Deeper in the profile the renovated pastures are significantly more compacted than native savanna but less compacted all the way down in the profile to almost 52 5 cm than non renovated pastures (Table 4) This indicates that grazing produces compaction deep in the soil but tillage for renovation partly reverses it at least in the more superficial soil layers (Figure 2)

Table 4 Average soil penetrability values in renovated and non renovated *Brachiaria dictyoneura* (Bd) pastures with rice in Matazul Llanos of Colombia October 1994

Treatment	Soil depth (cm)		
	3 5 17 5	17 5 35 0	35 0 52 5
	Penetrability kg/cm²		
Renovated Bd	12 0 c[1/]	21 0 b	29 0 a
Non renovated Bd	18 7 a	23 5 a	28 1 ab
Native savanna	16 3 b	17 8 c	21 2 c

1/ Data in the same column followed by the same letter do not differ significantly ($P<0.05$)

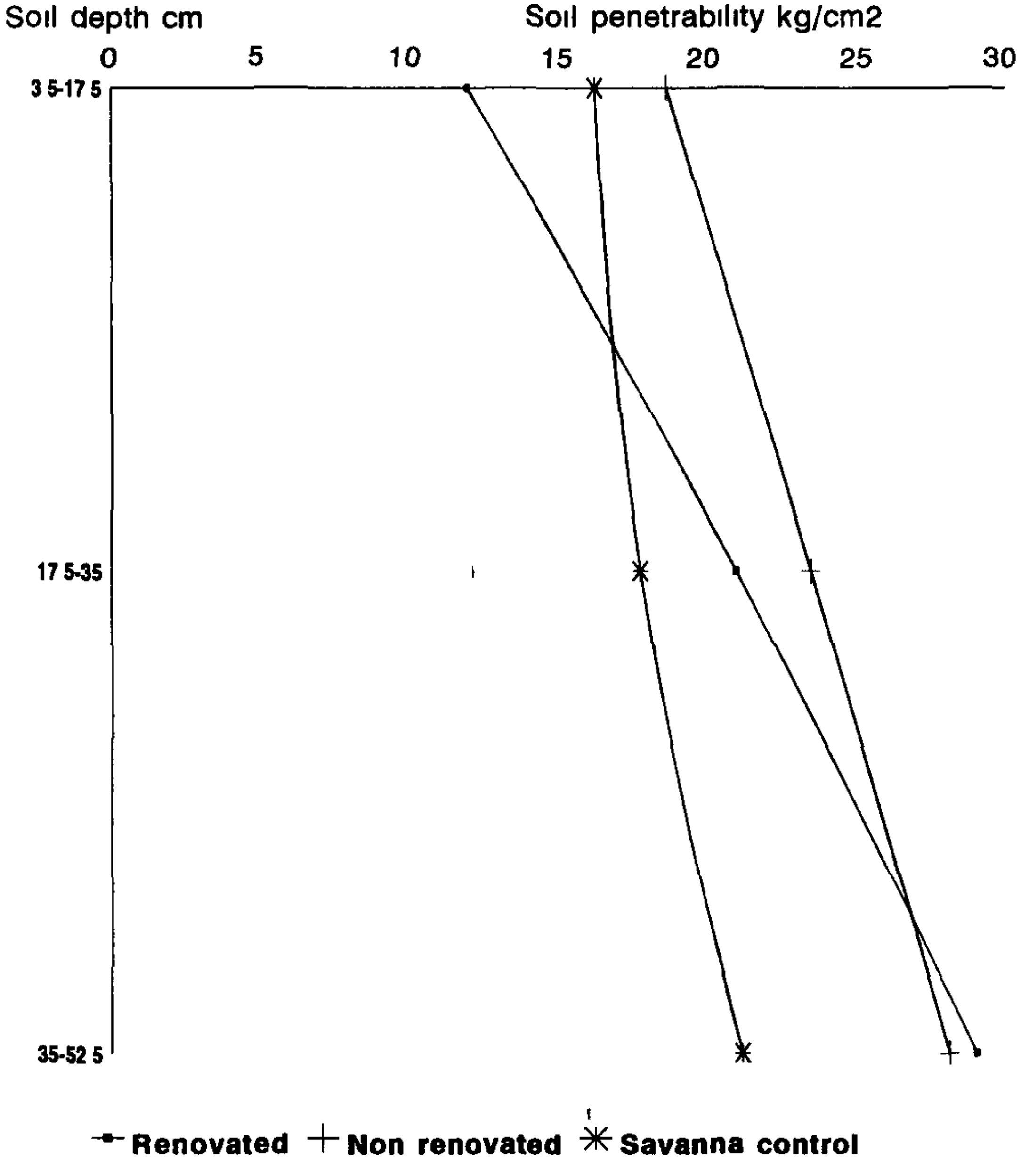

Figure 2 Average soil penetrability values in renovated and non renovated *B.dictyoneura* pastures with rice Matazul Llanos of Colombia october 1993

Other measurements different to penetrability such as infiltration rates and bulk density not reported here confirm our determinations and interpretation of the data

Trends in soil organic matter and microbial biomass in this trial contrast those reported for the monocrop prototype (see Projects T 02 AND TC 02) Microbial biomass C values for rice pastures are similar to those in rice monocrop or in native savanna whereas microbial biomass N was considerably higher (1 5 times) in rice pastures than in rice monocrop For microbial biomass P rice pastures either renovated or non renovated with rice in 1993 presented higher values (11 5 13 6 μg P/g) than either rice monocrop or native savanna (9 6 μg P/g) and therefore microbial C/P ratios are lower in rice pastures

The implication is that there is more organic matter of better quality turning over in rice pasture systems than there is in either rice monocropping or native savanna After six years of monitoring it is possible to state that the rice pastures prototype is a non declining system and from the microbiological point of view it is contributing to enhance the soil environment with all its consequences on plant growth

In summary rice pastures/cattle may affect soil physical properties but in a more reversible way than rice monocropping Added to this pastures contribute to microbial N and P microbial activity and organic matter quality and quantity being enhanced With time they may not only enhance the microbiological and chemical properties of the soil but also the physical properties (e g soil porosity through deep rooting pastures)

SUBPROJECT TL-01 1 WEED POPULATION ECOLOGY within Prototype Sustainable Cropping Systems for the Colombian Llanos Principal researchers *Albert Fischer* (Rice) *José I Sanz* (TL) Collaborator *Dennis Friesen* (TL)

A RATIONALE

As mentioned above weeds have been recognized as an increasingly relevant problem in existing as well as in CIAT s prototype cropping systems on acid soil savannas When land in the savannas is brought into cultivation weed populations increase (Friesen 1994) Ayarza (1994) reports that most production systems in the Cerrado had sustainability problems mainly due to weed infestations

Levels of weed infestation are variable in agricultural systems suggesting that certain variables could be adjusted to favour the crop in detriment to the weed thus minimizing herbicide input Also weeds appear to be related to sustainability decline and perhaps some of them could be useful indicators of resource base degradation within a system Therefore weed ecology as it relates to patterns of resource availability cropping systems and tillage should provide useful clues for enhancing or preserving the resource base and the sustainability of a system

The objectives of this study are first to study the population dynamics of species (native or introduced) associated with crops and pastures within prototype cropping systems in the Colombian Llanos as it relates to crop management and patterns of resource base availability Further clues about the desired ecological role of introduced vegetation will be sought and an attempt will be made to identify sustainability indicator species A second objective is to establish the economic relevance of weeds and the need for external weed management inputs by assessing crop losses and the ability of prototype cropping systems to suppress unwanted vegetation

B MATERIALS AND METHODS

The study was initiated in 1994 at the Matazul farm in the Colombian Llanos on field experiments being conducted there by Drs J I Sanz and D Friesen The preliminary data discussed here were obtained at three experiments with the following major features

The first experiment followed five consecutive years of sole rice three levels of P K Zn and dolomitic lime were combined with two cropping alternatives (rice monoculture and rice intersown with *Stylosanthes capitata)* Herbicides were used in rice and to establish the legume The second experiment followed rice after soybean the land was planted to rice in 1990 and then left as fallow until 1993 when rice was sown followed by soybean in the second semester In 1994 rice was sown alone or in association with forage species In the third experiment the land was previously under native savanna Rice was sown in 1994 and treatments sought different ways of incorporating savanna residues Since this is a long term study work will continue for three more years on these experiments

The minimum sampling area determined according to Bonham (1989) and Walter (1983) was within 10 quadrates of 0 5m^2 per plot In each experiment three subplots were defined within each plot 1) weedy check 2) weed free check and 3) standard weed control treatment where weed density (No /m^2) and cover (visual assessment) as well as rice yield were recorded For the long term study permanent points set in each plot where also weed density and cover are being monitored A zig zagging transect placed along the above points allows for additional cover estimates Evaluations are made at about 45 days after rice emergence and at harvestime Other data collected include Soil nutrients soil moisture and species biomass

Rice yields were analyzed by ANOVA and data on species Relative Abundance (a synthetic importance value defined as the average of the relative density and the relative frequency of a given species) were subjected to canonical discriminant analysis (CDA) following to Derksen et al (1993 and 1994) CDA allows to establish the main factors affecting the relative species composition of weed communities (Derksen et al 1993) Given a certain classification variable CDA derives linear combinations (canonical variables) which quantify the variability among the levels of the classification variable The coefficients of the canonical variable indicate the relative contribution of each species towards the canonical variable (Johnson and Wichern 1992 SAS Inst Inc 1989) The analysis was performed using SAS version 6 09

C RESULTS AND DISCUSSION

The species found are listed in Table 5 Rice monoculture developed weed populations that severely reduced its yields (Figure 3) even when herbicides were used (Table 6) In relating weed density to yield loss weed cover (as it relates to competition for light) was a much better expression of weed pressure than the actual number of weeds per unit area (Figure 3) Although to a lesser extent weeds also reduced rice yields in areas following rotations with other crops or native savanna (Table 6) Additions of P K and dolomitic lime to a weedy crop resulted in even higher losses from weed competition (Table 7)

Table 5 Species encountered in experiment following five years of rice monocropping Matazul 1994

Scientific name	Family	Vector letter[1]
Hyptis sp	Lamiaceae	A
Gymnopogon foliosus	Poaceae	B
Axonopus purpusii	Poaceae	C
Colocasia esculenta	Araceae	D
Centrosema pubescens	Fabaceae	E
to be classified		F
Emilia sonchifolia	Asteraceae	G
Croton rhamnifolius	Euphorbiaceae	H
Stylosanthes capitata	Fabaceae	I
Chamaecrista nictitans	Fabaceae	J
Paspalum multicaule	Poaceae	K
Digitaria sanguinalis	Poaceae	L

[1] Id t f I d m nat diag m

Table 6 Yields of rice in diverse cropping systems as affected by different levels of weed infestation Matazul 1994

Cropping System	Weed infestation			LSD 0 05 (kg/ha)
	Weedy	Weed free	Standard weed control	
After 5 years of rice monocropping	732	(kg/ha) 1652	1475	156
After soybeans	2072	2379	2186	117
After native savanna	1640	1873	1735	110

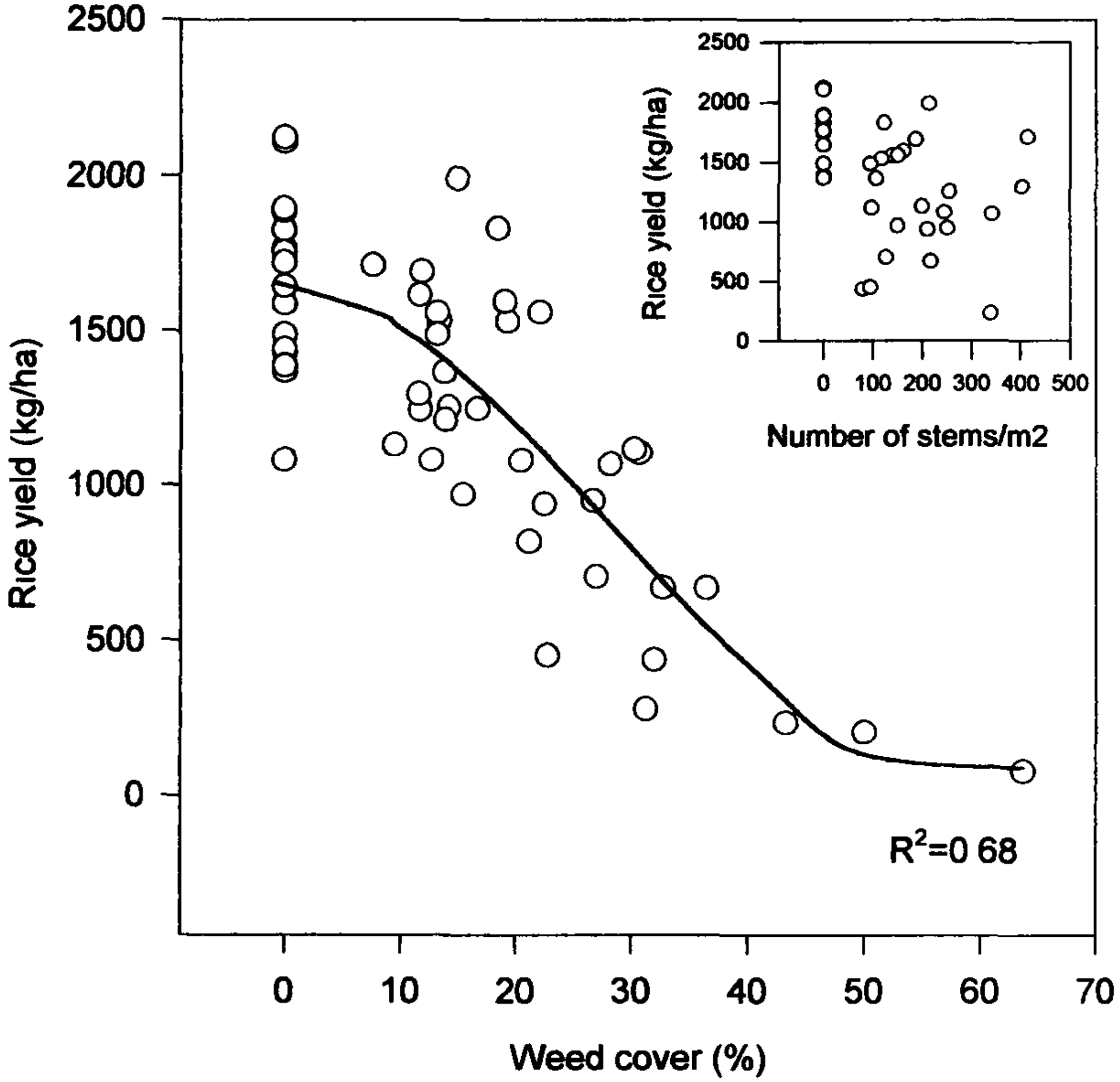

Figure 3 Yield reductions by weed infestations occurring after five years of continuous rice monocrop

Table 7 Effect of two levels of fertilization on rice yield losses (after five years of rice monocropping) from weed competition Matazul 1994

Fertilization			Weed infestation		
P	K	Lime	Weedy	Weed free	Weed control
				(kg/ha)	
25	50	300	1023	1726	1590
43	83	500	603	1787	1560

T mp w d f t t le f w th th m f rt l t tm LSD(0 05) 319kg/h
T mp re f rtili l l f the m w d i f t tl l l LSD(0 05) 501 kg/h

Since CDA cannot identify interactions two groupings were formed with different combinations of the different experimental effects studied (P K Lime rice monoculture and rice pasture) with data from the first experiment (rice after 5 years of monocropping) The first grouping appears on Table 8 and the second on Figure 4 In the first grouping the actual species composition of the groups were different when the squared Mahalanobis distances between the grouping centroids (data not shown) were compared (Table 8) According to the canonical coefficients *Axonopus purpusii* was the species mostly associated with lower fertility while *Centrosema pubescens* was mostly associated with the high fertility group (Table 8) In the case of the second grouping groups 1 and 3 represented different weed communities ($p<0\ 05$) as it happened when groups 2 vs 3 and groups 2 vs 4 were compared (data not shown) The canonical functions 1 and 2 explained 68 and 30% of the variability among treatments in the second grouping respectively (Figure 4) By the time data were recorded the newly intersown pasture had not affected the composition of weed communities as indicated by the lack of differences ($p>0\ 05$) between groups 1 and 2 and between groups 3 and 4 (data not shown) and by the short projection of the vectors of most species (Figure 4) Regarding the fertility levels *C pubescens* and *Paspalum multicaule* were indicators of higher fertility as shown by their vectors while *A purpusii* and *Digitaria sanguinalis* (a known ruderal) related to lower fertility (Figure 4)

The relevance of weeds in rendering rice monocropping unsustainable is clear from the far greater yield response to weeding than to increased fertility (Table 6) Some of these weeds could have been introduced with agriculture into the Llanos By fertilizing a weedy rice crop yields were reduced by the competition from weed communities that had shifted towards species who strive in such improved conditions as shown by the CDA analysis It had already been observed in similar environments that weeds could take up more Ca and K than rice (San 1994)

With the current weed pressure external weed control inputs for rice monocropping will be needed Also to deal with the present flora combinations of herbicides for a broader spectrum of control may be required This will have an impact on the farming economy the environment and on people s health CDA can help identify the ecological role of species within plant communities If the main ecological roles of relevant weeds and pastures are understood a pasture species could be chosen such that it would successfully seize the niches opened by the new agricultural inputs and substitute for some of the weeds A legume appeared strongly associated to higher levels of P and lime (Figure 4) this would also suit other forage legumes as well Therefore the CDA technique appears promising as a tool for plant population analysis and to identify species associated with certain patterns of resource availability Further studies will relate relative species abundance to other soil and agronomic parameters

Table 8 Partial results of the *canonical discrimination analysis for two levels of* fertilization with data from an experiment following five consecutive years of rice monocropping Matazul 1994

Group	P	K	Lime
1	25	50	300
2	43	83	500

Prob > Mahalanobis distance group 1 to 2 = 0 0073	
Highest total sample standardized coefficients for canonical variable	
Axonopus purpusii	1 76
Centrosema pubescens	3 55

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SUBPROJECT TL 01 2 ADOPTION OF LEY FARMING SYSTEMS IN THE COLOMBIAN LLANOS *Jose Vicente Cadavid and Joyotee Smith (TL)*

Production systems in the most intensified areas of the savanna (mainly in the center south of the cerrado and in the western savanna of Venezuela) are characterized by continuous monocropping and continuous tillage with heavy machinery While these systems are profitable they result in soil erosion compaction reduced microbiological activity declining quality of organic matter and loss of soil physical properties Pest build up is also a characteristic of these systems Semi intensive cattle ranches are also found in these areas where about 54% of the pasture area consists of planted pasture with stocking rates of about 1 24 heads per hectare of planted pasture The rest of the savanna is mainly characterized by extensive ranches consisting mainly of native savanna grasses and with low stocking rates often less than 0 2 heads per ha Pasture degradation in both these systems is common with bald patches leading to erosion and weed infestation

The crop pasture technology was developed in response to these problems An annual crop and a grass legume pasture is sown The annual crop is fertilized The pasture benefits from the residual fertility leading to quicker establishment and better pasture quality This makes it possible to graze the pasture immediately after the rice harvest After being grazed for about three years the pasture is renovated by planting the fertilized annual crop and the legume again

The concept of the crop pasture technology was based on a vision of intensified and sustainable agricultural development throughout the savanna Savanna intensification was expected to increase the returns to capital investment in the savanna and divert venture capital from the Amazon rain forest Intensification was also expected to reduce expansion of the agricultural frontier in the savanna and thus conserve plant and animal species Within this vision the objective of the crop pasture technology was to provide a sustainable alternative to continuous monocropping in intensified areas induce intensification in extensive areas without the resource degradation that characterizes continuous monocropping and to contribute to resource preservation by renovating degraded pastures and maintaining pasture quality The ley farming system was expected to achieve this by eliminating tillage during the pasture phase of the rotation and by maintaining pasture quality through the residual effect of the fertilizer applied to the annual crop The availability of acid tolerant rice and maize meant that remedial lime could be substantially reduced Grass legume pastures were considered to be more sustainable than pure grass pastures as farmers were considered to be unwilling to fertilize pastures in view of the long lead time involved in obtaining a return In addition to fixing nitrogen legumes also stimulate soil biological activity improve nutrient cycling and the nutritive value of forage and the system s carbon sequestration ability The system has also been shown to improve soil physical and chemical properties in comparison with annual crops and native savanna grasses At the same time cash flow versus pasture only systems was expected to be better because an annual crop would be available for sale a few months after the cost of pasture establishment was incurred and the pasture would be ready for grazing immediately after the crop harvest Pasture quality was expected to be maintained because the incentive to obtain cash revenue from the annual crop was expected to lead to a crop being sown every four years or so thus providing maintenance fertilizer for the pasture

As characterization of the savanna and analysis of land use dynamics proceeds some of the assumptions on which this strategy is based are coming under scrutiny The study reported here provides insights into one of these assumptions that technology can induce intensification in extensive areas If this assumption is correct technology development should be focused on intensive technologies If it is not correct a very different portfolio of technologies may be indicated which reconcile farmer demand for technology with strategies for ecosystem management

Economic analysis of the crop pasture technology with rice as the annual crop was carried out in 1990 based on trials under controlled experimental conditions The results gave attractive internal rates of return for beef production on medium and large scale farms but not on small scale farms indicating the existence of economies of scale Rice yields of 2 to 2 5 t/ha were sufficiently high to offset rice production costs and make a substantial contribution towards the cost of pasture establishment The rice pasture system also provided net positive income streams from the third year as opposed to five years for pastures established without rice While the technology offers these advantages it is also considered more capital and management intensive than either the traditional system based on native savanna grasses or planted pastures Some of the requirements of moving from the traditional system to improved pure grass pastures include land preparation fencing and the cost of grass seed Additional animals too may be required to obtain adequate returns from the improved pastures A major additional investment in management is also required The traditional system is capable of being managed by absentee landlords who make occasional visits to the farm and leave the day to day running of the farm to a relatively untrained hired hand The planted grass pastures require controlled grazing and rotation of animals to prevent over grazing on the one hand and to prevent the grass growing overly tall on the other Thus proper management by absentee landlords is likely to involve the expense of hiring a resident trained administrator The move to grass legume pastures is still more management intensive as it the correct balance between grasses and legumes have to be maintained This requires more control over grazing the establishment of more paddocks for rotation of animals and therefore more fencing Legume seeds are more expensive than grass seeds and more difficult to produce on farm Investment in expanding the herd is also necessary to recuperate the extra capital and management costs A shift to the ley farming system requires a combine harvester seed drill fertilizer and insecticide for the annual crop Most importantly though the crop component requires constant monitoring and therefore a change in attitude for those accustomed to pastures which can often be left unmonitored for several weeks without serious implications It appears therefore that native savanna grasses pure grass pastures grass legume pastures and ley farming systems lie along a continuum of increasing investment in capital and management When land values are low increases in production can be obtained more cheaply through area expansion than by intensifying inputs of capital and management per existing land area There is little incentive in maximizing returns per land area because land is an abundant resource Farmers prefer technologies which require minimum investment per land area This explains the prevalence of extensive grazing on native savanna grasses in areas of low land values Production is increased as the herd expands through natural increase over time As land is abundant the expanded herd is maintained by bringing more native savanna grasses under grazing by burning and by utilizing more low lying areas during the dry season As the herd expands beyond the limits of these practices over grazing occurs Planting a small area of improved pasture is an alternative to over grazing and is also a means of improving animal nutrition and therefore reproductive rates Adoption of small areas of improved pastures may be induced therefore through natural increases in herd size As land values increase it is only worthwhile holding on to land if high returns per land area can be obtained Thus investment in capital and management becomes more attractive When Increasing land values are induced by improved infrastructure marketing margins are reduced and output prices increase relative to input prices thus further inducing increased levels of input use Progression along the technology continuum is therefore likely to require increased land values and improved infrastructure In the absence of these preconditions technology is unlikely to be able to induce intensification Conversely intensification is unlikely if the pre conditions exist but technology which makes profitable intensification possible is absent

The study reported here investigates adoption of improved pastures in the municipalities of Puerto López and Puerto Gaitán in the department of Meta in the savanna of Colombia which is part of the Orinoquia region (Figure 5) 73 randomly selected farms were surveyed in 1989 and 1992 Farms smaller than 40 ha were excluded from the sample

The Colombian savanna is characterized by highly acidic soils (pH of 3 8 5) with high levels of aluminium (>80%) Annual rainfall is 1700 2500 mm with a dry season of 3 4 months Extensive grazing is the main form of land use with the greatest pert of the vegetation consisting of native savanna grasses Woody areas are found within the savanna and gallery forests are located along the river beds which are also the areas where small holders tend to be located Nomadic indigenous populations of hunters and gatherers are also found Most are undergoing a process of sedentarization and their numbers are declining fast

The department of Meta has grown faster than the rest of the country with GDP growth rates of 6 82% between 1970 and 1990 and 7 05% between 1980 and 1990 compared 3 5% to 4% for the rest of the country This is due to the recent evolution of commercial agriculture and petroleum related investment Meta contributes 3% of national agricultural product and 2 7% of the mineral output It should be pointed out however that the advanced agricultural area Piedmont is not part of the savanna ecosystem Villavicencio the main urban center in Meta has experienced rapid growth in the recent past as a growing distribution center for consumer goods to oil installations in the east Population density in Meta was 5 5 habitants per km sq in 1985 and is projected to increase to around 8 inhabitants by 1995 60% of the population lives in urban areas Thus rural population density is extremely low Transportation is a major constraint In the region of Orinoquia only 16% of roads are paved The towns of Puerto López and Puerto Gaitán in the study area are located 94 and 207 km respectively from Villavicencio The Villavicencio Puerto López road was paved in the early 1980s but road connections to farms away from the main road or hamlets are frequently nonexistent or only seasonally usable Recent major oil and natural gas discoveries in the eastern savanna are expected to lead to major improvements in main roads but farm to market roads are likely to remain poor in the short run Also significant improvements to the road connecting Villavicencio to the capital Bogota some 90 km away are now being carried out The study area can therefore be characterized as a traditional extensive cattle ranching area with unfertile soils very low rural population density and in the process of moving from poor to intermediate infrastructure The area can be considered fairly representative of the Latin American savanna except that it can be considered to be towards the unfavorable extreme in terms of soil fertility and in terms of infrastructure moving from the typical towards a more favorable direction The rate of change being experienced in the area is faster than in other areas such as the Brazilian savanna where frontier expansion is slowing down Survey data confirm that rapid changes are taking place in the study area Between 1979 and 1992 average farm size declined significantly from around 5000 ha to 1551 ha This is apparently the result of new farmers moving into the area 52% of sample farms were purchased after 1981 and of these around 22% were acquired after 1990 This has changed the character of the farming population in the area Prior to this time the bulk of farmers had owned their land for many years Some generally those with lower levels of education and therefore with lower opportunity cost resided on farm with subsistence as their main motive Others were absentee owners who came from traditional ranching families and had acquired their land through inheritance Both categories regarded land as a cheap abundant resource because it had been acquired without capital expenditure on their part Their priority therefore was a system requiring little management or capital investment per unit area By contrast in 1992 31% of farmers employed technically qualified resident administrators 32% paid for technical assistance 53% had their own tractor (Table 9) Educational levels were high with 41% having university education Only 21% lived on the farm 64% lived in Bogota The number of land purchases made for non production related motives are unknown However the data show that productive investments in land were occurring

Adoption of improved pastures in the study area increased at an annual rate of 14% between the 1978 1992 period In 1992 173 000 ha or 17% of the sample farm area was planted to improved pastures Only 18% of the improved area consisted of grass legume pastures and 1 5% was planted to the crop pasture technology 82% consisted of pure grass pastures (Table 10) The improved acid tolerant rice variety was only released in 1991 Therefore the low level of adoption of ley farming is not surprising The most widely grown grass *B decumbens* was never officially released in Colombia though it was released in a number of other Latin American countries starting with Cuba in 1987 The next most popular grass *B humidicola* was released in Colombia in 1992 and in other countries starting in 1985 In the case of both these grasses spontaneous adoption occurred with farmers obtaining materials from other countries and unofficially from experiment stations in Colombia and planting 125 000 ha by 1992 By contrast although the most widely grown legume *S capitata* was released in Colombia in 1983 adoption in 1992 was limited to 28 000 ha It is also notable that although only 17% of total farm area was planted to any type of improved pasture over 98% of farmers were adopters Apparently farmers started with a small area of improved pasture and expanded gradually as capital became available More than 90% of farmers increased their improved pasture area over time with improved pasture increasing relatively slowly (9 6% p a) between 1978 and 1981 and demonstrating a steeper increase (15 5% p a) after that period

Survey data reveal major differences between recommendations and farmers practices 31% of plots were not fertilized at establishment 96% received no fertilizer for maintenance purposes and 75% were never renovated 76% of farmers who planted *B decumbens* claimed that its productivity had declined compared to the first two years after establishment with 43% claiming productivity declines of 50% or more Casual observation indicates that overgrazing of improved pasture plots during the dry season may have contributed to pasture degradation

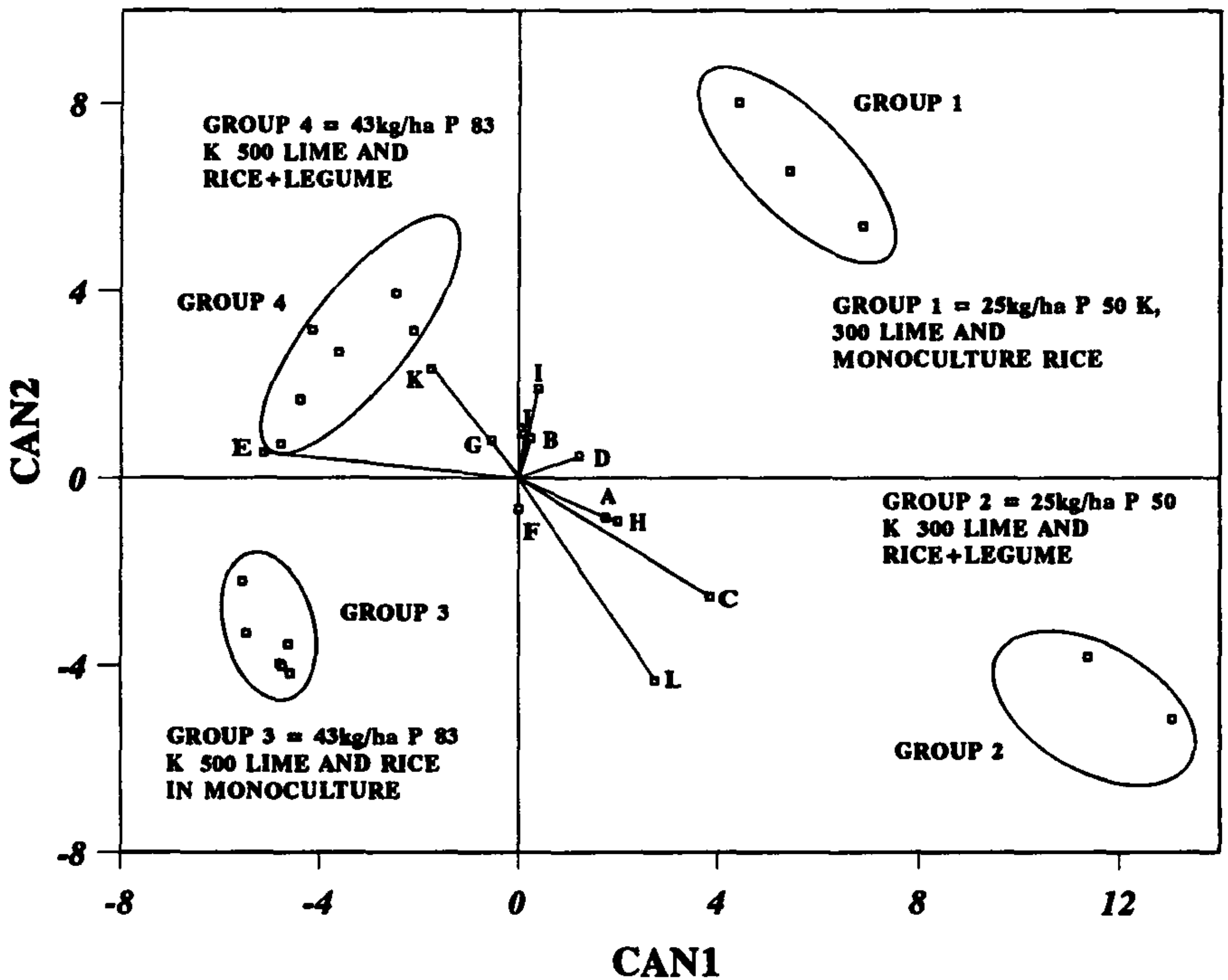
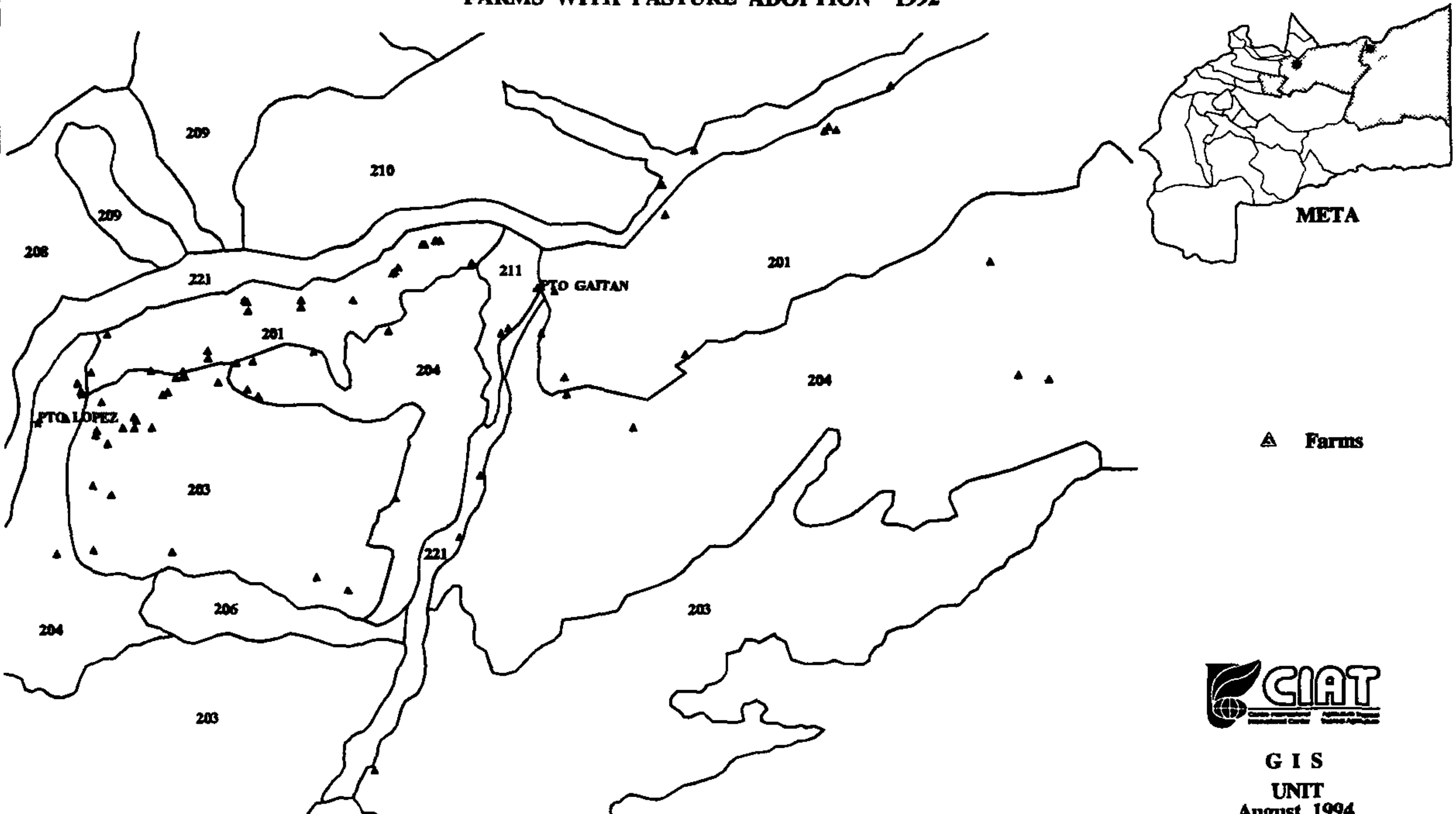


Figure 4 Canonical discriminant analysis ordination diagram of treatment clusters for two levels o combined with two cropping modes, and biplot scaling of weed species vectors indicating treatment as Symbols correspond to observation sites and their position is located based on relative species comp Significance of differences between treatments are discussed in the text Species association with s inferred from the direction of the vectors Vector length indicates the relative strength of associ

FIGURE 5 LAND SYSTEMS PUERTO LOPEZ   PUERTO GAITAN
FARMS WITH PASTURE ADOPTION 1992



Source Land in Tropical America. T T Cochrane

Table 9 Characteristics of study area 73 Farmers in Altillanura of Colombia 1992

Variables	Sum	Average	Std Dev	Maxim	Minim
Pasture area (ha)	18756	256 93	473 42	2900	1
Farm size (ha)	113199	1550 67	2276 75	16000	40
Area with forest (ha)	4820	66 03	99 49	500	1
Area without forest (ha)	108379	1484 64	2220 95	15600	32
Mechanizable area (ha)	66954	917 18	1170 07	7100	1
Tractor ownership (dummy)	39	0 5342	0 5022	1	0
Labor use (wages/ha year)	159 29	2 18	2 50	9 12	0 10
Loan (dummy)	18	0 25		1	0
Distance from Puerto López (Km)	6642	90 98	69 51	275	9
Farm administrator (dummy)	23	0 31		1	0
Residence at farm (days/year)		104 25	126 84	365	1
Resident of Santafé de Bogotá (dummy)	47	0 64	0 4821	1	0
Resident of Villavicencio (dummy)	11	0 15	0 3602	1	0
Farm resident (dummy)	15	0 21		1	0
University education (dummy)	30	0 41		1	0
Secondary education (dummy)	16	0 22		1	0
Primary education (dummy)	27	0 37		1	0
Age (years)		52 01	12 23	78	30
Years of farm ownership		12 09	10 73	44	1
Land title (dummy)	56	0 77	0 4255	1	0
Labor use/year	69286	945 10	875 97	6020	292
Family labor use/year	7139	89 27	186 70	730	0
Other labor use/year	62147	172 58	441 03	3245	0
Other activities (dummy)	62	0 85	0 36	1	0
Farm purchase 1981 1992 (dummy)	38	0 52	0 50	1	0
Experience with crops (dummy)	6	0 07		1	0
Technical assistance (dummy)	23	0 32	0 4677	1	0

Table 10 Improved pasture area[1] on farms[2] in the Altillanura of Colombia

Pastures Grass and Legumes	Area estimate[1] (ha)		% Farm area	
	1989	1992	1989	1992
Andropogon gayanus	4 453	7 129	5 0	4 1
Brachiaria decumbens	45 559	67 580	51 3	38 5
Brachiaria humidicola	26 479	57 476	29 8	32 7
Brachiaria dictyoneura	1 371	5 584	1 5	3 2
Other Grass	3 598	4 013	4 2	2 3
Total grass	**81 604**	**141 782**	**91 8**	**80 8**
S capitata + B decumbens	1 490	15 137	1 7	8 6
S capitata + B dictyoneura	847	5 558	1 0	3 2
S capitata + B humidicola	0	6 765	0 0	3 9
S capitata + A gayanus	2 480	621	2 8	0 4
C acutifolium + A gayanus	339	0	0 4	0 0
Other associations	1 794	2 699	2 0	1 5
Total grass + legume pastures	**6 950**	**30 780**	**7 8**	**17 3**
Legumes[3]	323	277	0 4	0 2
Crop + Pasture		2 737		1 5
Total improve pastures	**88 877**	**176 576**	**100 0**	**100 0**
Area nature savanna grass	871 459	850 408	90 7	82 9
Total farm area	**960 336**	**1 025 984**		

1/ Error of estimation 20% Level of confidence 80%
Survey 86 and 82 farms in 1989 and 1992 respectively

2/ Farms greater that 40 ha 728 localized in Puerto López and Puerto Gaitán (Meta Colombia)

3/ Legumes (Seed bed) *S capitata A pintoi C acutifolium P facilities*

Around 75% of producers had cow and calf operations The rest also carried out some fattening Although the number of producers who fattened increased from 21% to 28% between 1979 and 1989 the difference was not statistically significant

Time series regression analysis over the 1978 1992 period revealed that the construction of the paved road between Villavicencio and Puerto López had a statistically significant effect on the net accumulated area planted to improved pastures as did increases in real terms in agricultural GDP and increases in the supply of meat (Table 11) The paved road would be expected to stimulate the use of input intensive technologies by increasing land values and reducing input/output price ratios while the other variables represent generally favorable market conditions for agriculture

Table 11 Time series multiple regression estimates of factors determining cumulative net area in improved pastures 1978 1992

Exogenous Variables	Signs and Coefficients	t stat	Level of Signific	R^2_j	D W	F
Constant	39 81	2 76	0 020	0 93	1 44	51 02
Agricultural GDP[1/] (Ln)	+2 59	3 27	0 008			
Cattle Supply (Ln)	+1 07	1 85	0 093			
Paved Road (dummy)	+0 65	3 94	0 003			
Number of released forages	+0 08	1 55	0 15 ns			
B/C index	+		n s			

1/ Constant 1978 pesos

R^2_j Coefficient of multiple correlation adjusted
D W Coefficient of autocorrelation Durbin Watson
F F statistic
n s Not significant at the 0 10 level
Ln Natural logarithm

Cross sectional regression analysis showed that adopters were those who invested in their farms tractor owners those who had farm administrators those who paid for technical assistance Other factors indicated that adoption increased with land values The area with improved pastures was higher on farms with legal land titles and close to Puerto López Also there was a negative relationship between improved pasture area and forested farm area Extensive forested area indicated land abundance which made the adoption of intensive technologies unnecessary (Table 12) Contrary to widely held views residence on farm was negatively related to adoption This may be because those who resided in urban centers had better access to capital and were therefore more likely to adopt technologies which required considerable capital investment These more capitalized farmers were able to adopt a management intensive technology in spite of living off farm by hiring trained resident administrators Unexpectedly years of education were negatively related to adoption When asked about their requirements farmers said they wanted nutritious persistent pastures adapted to their soils and resistant to pests Most importantly farmers wanted pastures that met these conditions under their level of management Persistence of legumes under farmer management was seen as a particular problem Farmers therefore appear to be unwilling to change their level of investment and management in order to take advantage of new technologies

Table 12 Cross section multiple regression estimates of factors determining area in improved pastures 73 farms 1992

Exogenous Variables	Signs and coefficient estimates	t Statist	Level of signif	Coefficient of Correlation
Constant	+133 835	0 799	0 427	
Area with forest (ha)	0 995	2 474	0 016	0 11
Area without forest (ha)	0 049	1 873	0 066	0 42
Mechanizable area (ha)	+0 378	8 058	<0 001	0 69
Tractor ownership (dummy)	+123 985	1 720	0 090	0 37
Distance from Puerto López (km)	1 103	1 838	0 071	0 08
Technical assistance (dummy)	+126 671	1 563	0 123	0 37
Farm administrator (dummy)	+135 128	1 729	0 089	0 42
Residence at farm (days)	0 588	1 955	0 055	0 16
Education (years)	96 109	2 058	0 044	0 15
Land title (dummy)	+175 608	2 027	0 047	0 17
$R^2_{\ I}$ = 0 6695 F = 15 58 D W = 2 32				

$R^2_{\ I}$ Coefficient of Multiple Correlation Adjusted
D W Coefficient of Autocorrelation Durbin Watson
F F statistic

The results of this study are consistent with the theoretical prediction that the pre conditions of increasing land values and improving infrastructure have to be met before technologies of increasing capital and management intensity are adopted Grass legume pastures and ley farming systems appear to require a higher level of investment in capital and management than farmers in the study area are willing to incur at this time Even the recommendations for pure grass pastures appear to be too intensive at current land values and at current levels of infrastructure In fact the main driving force behind adoption may have been natural increases in herd size There are indications however that major improvements in infrastructure are likely in the study area and this is likely to lead to the adoption of more intensified technologies *It would be very important therefore to make a detailed study of* farmers objectives resources and practices to guide the modification of the technology to better meet farmers needs The pay off may be particularly high in view of the technology s apparent ability to sequester carbon at a time when international markets in carbon sequestration services appear to be emerging It should be pointed out however that this prognosis may be undermined if guerrilla activity and the drug trade continues unchecked

A large part of the savanna in Latin America is likely to remain with poorer infrastructure than the study area in the medium term Characterization of the heterogeneity within the savanna is required to more accurately target existing technologies and develop a profile for appropriate technological alternatives An adoption study in the most intensified areas of the savanna such as the center south of the Brazilian savanna which on an ex ante basis appears to be the most appropriate target area for the technology is clearly indicated A land use plan for the savanna based on both bio physical and socioeconomic considerations is needed to identify whether agricultural development is desirable in remote areas of the savanna or whether these areas should be set aside for conservation purposes In particular the importance of preserving native savanna for biodiversity purposes needs to be emphasized The fact that the most promising legume currently available *A pintoi* is a native species from the Brazilian savanna is testimony to the importance of preserving biodiversity *A pintoi* s persistence may also imply that native species may be more robust under farmer management For those less intensified areas where agricultural development is part of the strategy technologies which save labor capital and management but use land in abundance may be more appropriate In particular legumes which were developed with areas of poor infrastructure in mind where access to fertilizer may be difficult appear to require major decreases in their capital and management requirements if they are to fulfill the role for which they were originally intended It may also be worthwhile investigating whether in areas of poor infrastructure where stocking rates are likely to be low sustainable production can be achieved through the development of technologies which combine the management of native grasses with pure grass planted pastures This would build on farmers current practice thus increasing the chances of acceptability Survey results imply that natural increases in herd size may be propelling adoption of pure grass pastures to some extent Adaptation of the technology to the requirements of these unintensified farms is required to prevent them from taking the over grazing route In this context it should be noted that the current technology for recuperation of degraded lands the crop pasture technology is too intensive for these areas An alternative technology which builds on the farmers strategy of utilizing low lying areas and planting small areas of pure grass pastures may be more adoptable A detailed understanding of current practices and the objectives of the different categories of farmers in the savanna including small scale farmers is clearly indicated It should also be pointed out that analysis of the economics of the new technologies and evaluation of their ecological impact has been based so far on data from controlled experiments Validation of these results under farmers practices is required Also very little attention so far has been given to offsite impacts such as the effect of increasing demand for fencing materials on the preservation of gallery forests Live fencing using forage trees may be an option worth investigating

Subproject TL 03 1 vegetation and ecology of the serranıa natıve pastures of the eastern plaıns of Colombıa (Llanos) *G Rıppsteın (CIAT/CIRAD EMVT) J K Broekhuıjsen (UW) A G E Peters (UW) G Escobar (TL)*

I INTRODUCTION

The Eastern Plaıns savanna of Colombıa (Llanos Orıentales) occupıes almost 17% of Colombıa ıs surface area (Fıgure 6 Tables 13 and 14) Nearly 80% of thıs area consısts of a grass vegetatıon where extensıve cattle raısıng ıs beıng practıced The rest of the area ıs covered by forest or ın use for agrıculture Around 40% of the Llanos of Colombıa are covered by Serranía (Serranía and Altıllanura ondulada) The people of the Llanos have gıven thıs name to the hılly savanna landscape whıch ıs sıtuated ın the South of the Llanos Although ıts surface area ıs very extensıve the Serranía ıs not ıntensıvely used because of ıts dıffıcult accessıbılıty and the very poor qualıty of the majorıty of ıts soıls

Table 13 Colombıan Eastern Plaın savannas (Llanos)

	000 hectares	%
WELL DRAINED SAVANNA		
Flat Altıllanura	3 438	21 2
Ondulated Altıllanura and Serranía (sloppy)	6 385	39 3
Fluvıal banks	1 245	7 7
Food hılls	925	5 7
BAD DRAINED SAVANNA		
Old alluvıum	4 934	30 4
TOTAL LLANOS	16 927	100 0
TOTAL COLOMBIA	103 900	

Source Vera and Seré 1985

Table 14 Relıef repartıtıon ın Serranía and Altıllanura ondulated (7 farms)

	Hectares	%
Total	25200	100
Serranía	15600	62
Ondulated savanna	9300	37

The Llanos Orıentales ıs sparsely populated The most ımportant actıvıtıes wıthın the area are cattle ranchıng and subsıstence agrıculture Through the development of an ınfrastructure commercıal agrıculture wıll be more and more practıced ın the Llanos Orıentales Thıs development ıs occurrıng especıally ın the flat savannas Altıllanura plana whıch are more accessıble and have a hıgher soıl fertılıty Cattle ranchıng well be forced to move to areas whıch are less suıtable for agrıculture such as the Serranía

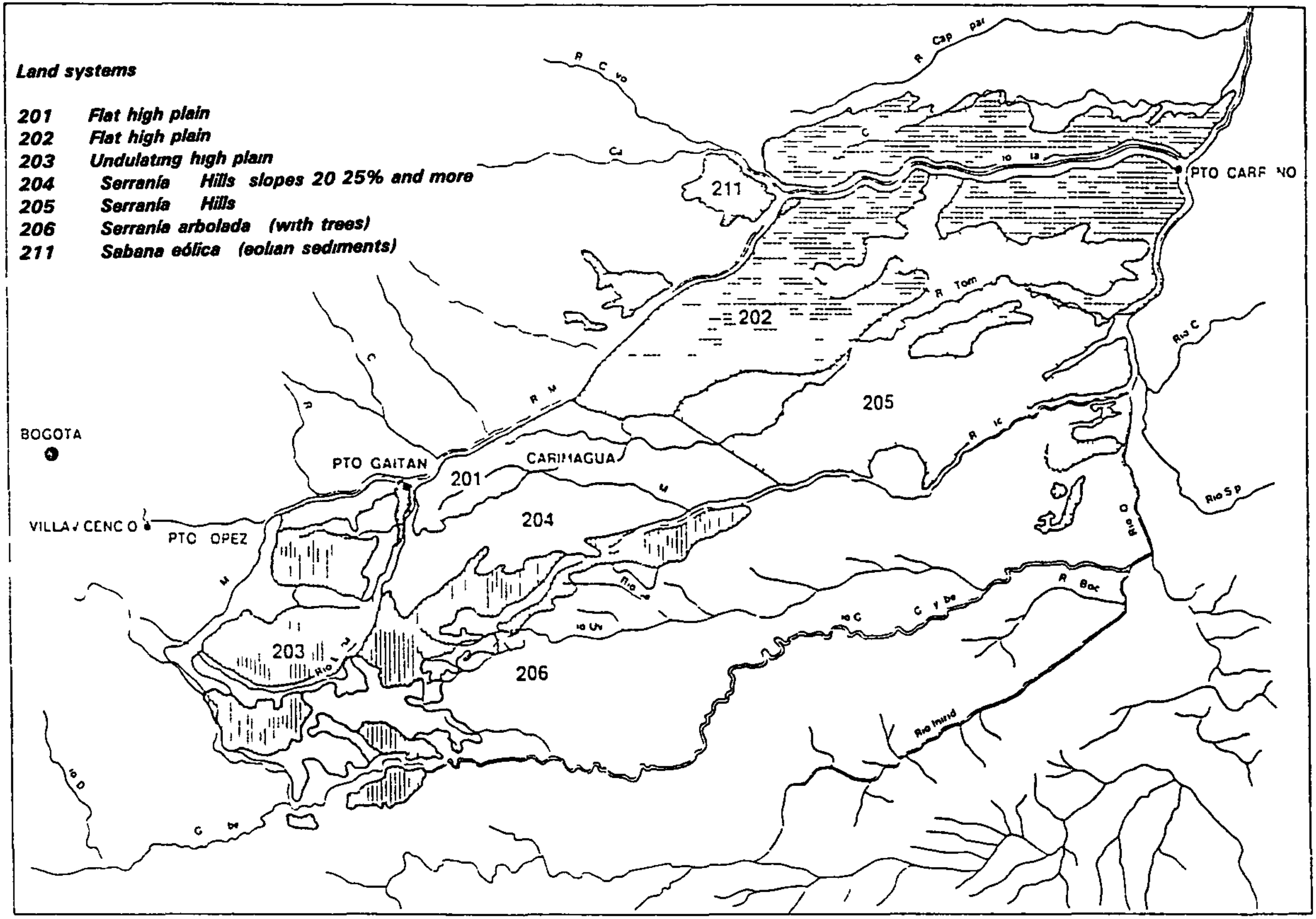


Figure 6 Principal Llanos savanna land systems
(Adapted from Cochrane 1985)

Little is known about the Serranía native pastures Therefore an extensive inventory research on the Serranía flora and ecology was begun in 1993 and 1994 with Dutch and French students This research is done on farms which are situated in different parts of the Serranía In this way an overall picture of the Serranía can be obtained

The relief of the Serranía can be divided into different topographic units the top of the hills the slopes the dry lowlands the humid lowlands and the floodplains Several ecological scientists take the view that differences in the natural Serranía vegetation coincide with these topographic differences This opinion is tested in these first studies

We present here some results of the first survey made in 1993 by Dutch students (J K Broekhuijsen and A G E Peters) from the Wageningen Agricultural University for their thesis in grassland science (Prof Dr ir L t Mannetje) An other survey was made in the same areas in 1994 by a French student (Cécile Grollier from ISTOM (Institut Supérieur Technique d Outre Mer) However the analysis of these data is not yet completed

2 METHODS

2 1 Selection of the plots

Five farms and two reserves for indigenous people were selected to carry out the research These farms and reserves are all situated in the Serranía They were selected on the basis of representativeness and accessibility Because of the expanse of the Serranía the selected farms and reserves were situated in different parts of the Llanos In this way an overall picture of the Serranía is obtained

Within each farm and reserve area several plots were selected where vegetation and soil samples were taken The plots were situated at sites which are considered typical for the Serranía the top of the hills (los altos) the slopes (las pendientes) the dry lowlands (los bajos secos) the humid lowlands (los bajos humedos) and the floodplains (los bajos inundables) Differences in vegetational composition and/or soil types among the topographic sites can be recognized in this manner

The size of the plots was 20 x 20 meters This is the minimum area required for a representative survey of a grassland vegetation (Matteucci 1982)

2 2 Fieldwork

2 2 1 Transects

To get a measurement of the species frequency and abundance transects were made in every plot (28 3 meters and only 10 meters when the vegetation is more homogeneous) A needle was placed at every 10 cm The species or bare ground touched by the needle were recorded for aerial cover and relative aerial cover The (relative) aerial cover is the vertical projectation of the above ground plant parts and can exceed 100% due to overlapping of different species

2 2 2 Braun Blanquet method

Braun Blanquet have developed a hierarchical classification system to determine differences in vegetation types or fytocoeneose A vegetation type or fytocoeneose is defined as a relative homogeneous vegetation the internal floristic differences are smaller than the differences with the surrounding vegetation

The method of Braun Blanquet starts with a description of the total floristic composition of a vegetation type within a minimum area The minimum area required is determined empirical and depends on the type of vegetation (grasslands woodlands etc) All species are identified and their proportion in the vegetation type or fytocoeneose is determined

A combined scale of cover and abundance is used in the hierarchical system of Braun Blanquet (from Matteucci 1982)

r	=	one or a few individuals
+	=	cover less than 5% and occasionally
1	=	abundant but with a low cover or less abundant and with a greater cover but always less than 5%
2	=	very abundant and less than 5% cover or less abundant and 5% to 25% cover
3	=	25% to 50% cover independent of the number of individuals
4	=	50% to 75% cover independent of the number of individuals
5	=	75 to 100% cover independent of the number of individuals

After this scale division a syntax table is made in which vegetation types with great similarity in species composition and abundance are grouped together

The Braun Blanquet values used in the research were given on the basis of the relative aerial cover determined with the transects The value + was given to species with a relative aerial cover of 0 1% the value 1 to species with a relative aerial cover of 1 5% After the transects were taken the plot area was researched for species which were not found on the transects These species were given the value r of the Braun Blanquet scale The values of Braun Blanquet are used in the cluster analysis TWINSPAN and CLUTAB

2 2 3 Identification of species

The species were identified in the field as much as possible Species which could not be identified in the field were brought to the Research Station of Carimagua There they were identified with the help of a Herbarium of Llanos species and several determination keys If it was not possible to identify the species in Carimagua they were sent to Professor Eugenio Escobar the director of the Herbario Jose Cuatrecasas of the National University of Colombia (Palmira) who was the principal determiner of the species A Herbarium was made of all different species of the Serranía vegetation

2 2 4 Aerial biomass

To get a measurement of the aboveground biomass (phytomass) quadrants of 1*1 m were randomly placed in the plot area Aerial biomass was measured for the standing vegetation that is available for cattle at a certain time It only deals with the quantity of the vegetation not with the quality The vegetation within the quadrant was cut with a pair of grass scissors at ground level Next the material was divided in dead (dry) and living (green) material put in different paper bags and weighed In this way one gets an impression of the green material that is still available for cattle Afterwards the living material was dried in an oven and weighed again This material was ground and sent to the CIAT Laboratory in Cali for a chemical analysis

Dividing the aerial phytomass by the number of days of regrowth gives the production

2 2 5 Soil samples

Soil samples were randomly taken in every plot to get an impression of the water content the texture and the chemical composition of the soil All soil samples were taken to 10 cm depth The dried soil samples were sent to the CIAT Laboratory in Cali for chemical and textural analysis

2 2 6 Interviews

Interviews on the management of the Serranía were taken with the encargados (the managers) of each farm the indigenous people of San Luis del Tomo and an indigenous farmer These interviews are elaborated in the paper Que quenta Llanero a report on a practical period written by Lonneke Peters and Jeannette Broekhuijsen (1994)

2 3 Chemical analyses

The chemical analyses of the vegetation and soil samples were executed in the Laboratory of CIAT s Tropical Pastures Program in Cali The methods used are all described in *Métodos Químicos para el Análisis de Suelos Acidos y Plantas Forrajeras* written by J G Salinas and R García in 1985 The nitrogen content of the plants is determined by the Bremer method the phosphorus content of the soil by the Bray II method

2 4 Cluster analyses

Cluster analysis of ecological data is one of the major methods used since the study of ecology started In cluster analysis data of species and sites are rearranged in a table in order to identify community types Each community type is characterized by a typical species combination (Tongeren in Jongman et al 1987) The central questions in cluster analysis are is there a connection in the distribution of the species across the samples and is it possible to recognize certain clusters with roughly the same samples In cluster analysis a calculation method is used which can look for such a classification The underlying model is based on the idea that there are few community types each with a specific species composition (Looman 1984)

In this research the cluster analysis TWINSPAN and CLUTAB are used The vegetation data were first analyzed with the TWINSPAN method A table was obtained in which the samples and species were ordered into clusters This ordered table was used in the CLUTAB program The outputs of this program were then used to make a synoptic table of the TWINSPAN output

2 4 1 TWINSPAN

TWINSPAN (TWo way INdicator SPecies ANalysis) is a program developed by Hill (1979) It arranges multivariate data in an ordered two way table by classification of individuals and their attributes First a classification of the samples is made by grouping like samples with like Next a species division is made according to their ecological preferences These classifications are then put into an ordered two way table that expresses the species synecologic relations This arrangement approximates one result of Braun Blanquet table (Hill 1979)

The model used in TWINSPAN is based on the phytosociology premise that each group of sites can be characterized by a group of differential species According to Hill (1979) a differential species can be defined as a species with clear ecological preferences so that its presence can be used to identify particular environmental conditions

However TWINSPAN is an indirect gradient analysis which means that the environmental factors are not directly put in the two way table One has to look for the gradient in the table and compare different environmental factors with this gradient It can thus be possible that the gradient calculated in TWINSPAN has no ecological meaning

The ordered two way table is made by repeated dichotomy TWINSPAN is a divisive cluster method that starts with all samples as a group This group is divided into two smaller groups and this is repeated until the ultimate division can be obtained with the data used This way of clustering is based on the idea that large differences should prevail over less important smaller differences (Tongeren in Jongman et al 1987)

A species gradient is calculated by reciprocal averaging Each species is given a number After that the scores for the samples is calculated by averaging the scores of the species A dichotomy is obtained by dividing the group of samples at the middle of the gradient The species are put in the group for which they are the most typical This process is repeated until a stable set of scores is obtained on which the gradient can be based The dichotomies are indicated in the two way table with 0 and 1 at the right and bottom of the table

2 4 2 CLUTAB

After the identification of clusters with TWINSPAN it is useful to summarize the results for each cluster into a synoptic table In this way the two way table of TWINSPAN becomes smaller and easier to interpret because comparable samples are put together into one cluster In the CLUTAB program a cluster is presented in one column in which for a species the frequency average abundance (calculated over the whole cluster) or the characteristic abundance (calculated over the samples in which a species really appears) are presented With these tables a synoptic table can be made

The species are arranged in CLUTAB according to their characteristics

2 4 3 Condensed format file

A condensed format file of the fieldwork data is needed to process them in TWINSPAN and CLUTAB In a condensed format file the list of species distribution frequency and Braun Blanquet values is reduced to a minimum

3 RESULTS

3 1 Identification of species

In the whole research area 173 different species were found which belong to 40 different families A complete list of all these species is added to this paper as Annex 1

Some species are not completely identified They are represented by their family name and a question mark (eg Cyperaceae ?) or by the additive sp (eg Alternanthera sp)

The 40 different families are divided in five groups The first group represents the grasses or Poaceaes The second group are the Cyperaceaes The third group are the legumes to which the Caesalpiniaceae Fabaceae and Mimosaceae families belong Monocotyl species the fourth group are the Amaryllidaceae Araceae Haemodoraceae Iridaceae Palmae and Xiridaceae families The other families all belong to the last group the Dycotyl species

3 2 Botany biodiversity

Two different zones were already investigated in the Llanos the flat area (Altillanura plana) and the more disturbed area (Serranía)

If we compare the native vegetation of the Altillanura plana (survey in Carimagua) with the Serranía (Table 15) we can observe that only 89 species are common for both sites (for a total of 173 for the Serrania and 158 for the Altillanura) but a majority of families are common

Table 15 Biodiversity in Altillanura and Serranía

	Species	Family	Poaceae	Legumes	
	Frequency				
Altillanura	158	43	45	23	Fabaceae Mimosaceae Caesalpinaceae
Serranía	173	39	53	26	
In common	89	34	35	13	

The native savanna of the Llanos is nevertheless poor in species (relative to Cerrados for example) but rich in *Paspalum* (12 different species and varieties) and in *Panicum*

The vegetation is also poor in good productive legumes but quite rich in number of these families

3 3 Frequency abundance and distribution of species

The frequency and abundance of species was determined with the transects A complete list of species distribution frequency and Braun Blanquet values for the different plots was calculated (see Annexes 1 and 2)

3 4 Identification of community types (Annex 2)

The output of the TWINSPAN analysis (not added to this paper) shows a great difference between the sites Therefore it is difficult to identify certain clusters with the same samples Yet roughly 4 clusters or community types are identified Five samples (relieves) are present in the first cluster 11 in the second 7 in the third and 8 in the fourth cluster The distribution of the samples over the 4 clusters is shown in Annex 2 The vertical lines are the boundaries between the clusters

It seems that the gradient on which the samples are divided has a relationship with the topography the top of the hills and the slopes are put together in clusters 2 and 3 and the humid lowlands and the floodplain are put together in clusters 1 and 4 The dry lowlands are present in all four clusters The four clusters identified in the TWINSPAN analyses were processed in the CLUTAB program

The four TWINSPAN clusters were rearranged in the CLUTAB outputs in the order 3 2 1 4 This again shows a relationship with the topography The clusters with the top of the hills and the slopes are put first and they are followed by the lowland clusters Within the different CLUTAB tables 74 characteristic species are identified 14 common species and 85 rare species No accompanied species were recognized within the different clusters

After the processing of data in CLUTAB a synoptic table was made This table is given in Annex 2 Lines are drawn in this table The vertical lines are again the boundaries between the different clusters or community types The horizontal lines are the boundaries between the species which are typical for one or two clusters Species which are typical for a cluster or community type are thus put together in a square The different squares are put on a diagonal line along the gradient

Five characteristic species are present in the first community type The species frequency for that cluster is put between brackets The characteristic species for the first community type are (Table 16) *Chamaecrista hispidula* (42% family Caesalpiniaceae) *Rhynchospora pubera* (28% family Cyperaceae) *Eriosema* sp (28% family Fabaceae) *Trachypogon vestitus* (100% family Poaceae) and *Paspalum pectinatum* (85% family Poaceae)

The second community is identified by five characteristic species These are *Mesosetum pittieri* (81% family Poaceae) *Trachypogon plumosys* (72% family Poaceae) *Rhynchospora globos* (54% family Cyperaceae) *Galactia glaucescens* (27% family Fabaceae) and *Borreria capitata* (27% family Rubiaceae)

For the third community six characteristic species are identified These are *Eriosema simplicifolium* (80% family Fabaceae) *Dichromena ciliata* (60% family Cyperaceae) *Andropogon selloanus* (60% family Poaceae) *Chamaecrista* sp (40% family Caesalpinaceae) *Micona rufescens* (80% family Melastomataceae) and *Paspalum* sp (60% family Poaceae)

The characteristic species for the last community are *Cupea calophylla* (62% family Lythraceae) *Lindernia diffusa* (62% family Scrophulariaceae) *Schizachirium brevifoliumra* (62% family Poaceae) *Andropogon bicornis* (50% family Poaceae) *Bittneria mollis* (50% family Sterculiaceae) *Rhynchospora corymbosa* (25% family Cyperaceae) *Croton trinitatis* (25% family Euphorbiaceae) *Hyptis verticillata* (25% family Labiatae) *Desmocellis villosa* (25% family Melastomataceae) *Mimosa pudica* (25% family Mimosaceae) *Ludwigia decurrens* (25% family Onagraceae) *Gymnopogon fastigiatus* (25% family Poaceae) and *Sauvagesia erecta* (50% family Ochnaceae) This last community has the most characteristic species although the amount of samples in this cluster is not the highest

Table 16 Plant communities and characteristic species of the Serranía

Plant communities	Characteristic species
1 Top of hill and slope	*Chamaecrista hispidula* *Rhynchospora pubera* *Eriosema* sp *Trachypogon vestitus* *Paspalum pectinatum*
2 Dry lowlands	*Mesosetum pittieri* *Trachypogon plumosus* *Rhynchospora globosa* *Galactia glaucescens* *Borreria capitata*
3 Humid lowlands	*Eriosema simplicifolium* *Dichromena ciliata* *Andropogon selloanus* *Chamaecrista* sp *Miconia rufescens* *Paspalum* sp
4 Floodplain	*Cupea calophylla* *Lindermia diffusa* *Schyzachirium brevifolium* *Andropogon bicornis* *Bittneria mollis* *Rhynchospora corymbosa* *Croton trinitatis* *Hyptis verticillata* *Desmocellis villosa* *Mimosa pudica* *Ludwigia decurrens* *Gymnopogon fastigiatus* *Sauvagesia erecta*

The highest average number of species is found in the fourth community (cluster 4 25 4) The lowest in the second community (cluster 2 18 3) although this is the cluster with the most samples One can conclude that the average number of species is lower at the top of the hills and the slopes than in the lowlands

3 5 Areas covered by the plant communities

An estimation of the relative areas of these different topographic sites or plant communities was made on five farms which cover of more than 10 000 hectares (Table 17) the potential land use is also proposed

Table 17 Serranía topography (on 5 farms)

Type of relief	%	Potential use
Top and slopes of the hills	54	Pasture only
Dry lowlands	24	Agriculture/pasture
Humid lowlands	14	Agriculture/pasture
Flood plains	7	Pasture (dry season)/agriculture
Total 5 farms	100	

Figure 7 shows the average number of species at all topographic sites The greatest number of different species was found in the humid lowlands (almost 30 average 29 8) and the lowest at the top of the hills (less than 15 average 14 7) The average number of species increases from the top of the hills to the humid lowlands However the average number of species decreases from the humid lowlands to the floodplain (to average 19 7)

There is not much difference between the topographic sites in the number of grasses found The greatest number of different grasses was found in the humid lowlands (average 9 3) the lowest at the top of the hills (average 6 6) The most different Cyperaceae were found at the slopes (average 3) The average number of legumes found is highest in the dry lowlands (namely 3 9) The number of different monoctyl species found is highest in the humid lowlands (namely 1) Most different dicotyl species are found in the humid lowlands (namely 14 8)

3 6 Relative aerial cover

In Figure 8 the relative aerial cover for the five different topographic sites are given The relative aerial cover is a measure for the cover percentage of all species separately The relative aerial cover of the grasses is highest at all sites The relative aerial cover of the other species is much lower

3 7 Aerial biomass and production

Figure 9 shows the difference in biomass that is related to the regrowth time after burning The burning date was known for 18 plots and for these plots the regrowth days after burning are calculated The aerial biomass for the first 90 days is very low averaging 415 kg/ha After these days the biomass increases tremendously even up to 5927 kg/ha although this must be seen as an exception After 30 days of regrowth the part of green matter is low

The aerial production is given in Figure 10 but the real comparison between site is difficult because of the different grazing intensity

3 8 Pasture quality

The protein P and Ca (Figures 11 and 12) contents are higher in lowland pastures They are not only related to green matter percentage (are of the plant or soil moisture content) but also with soil fertility

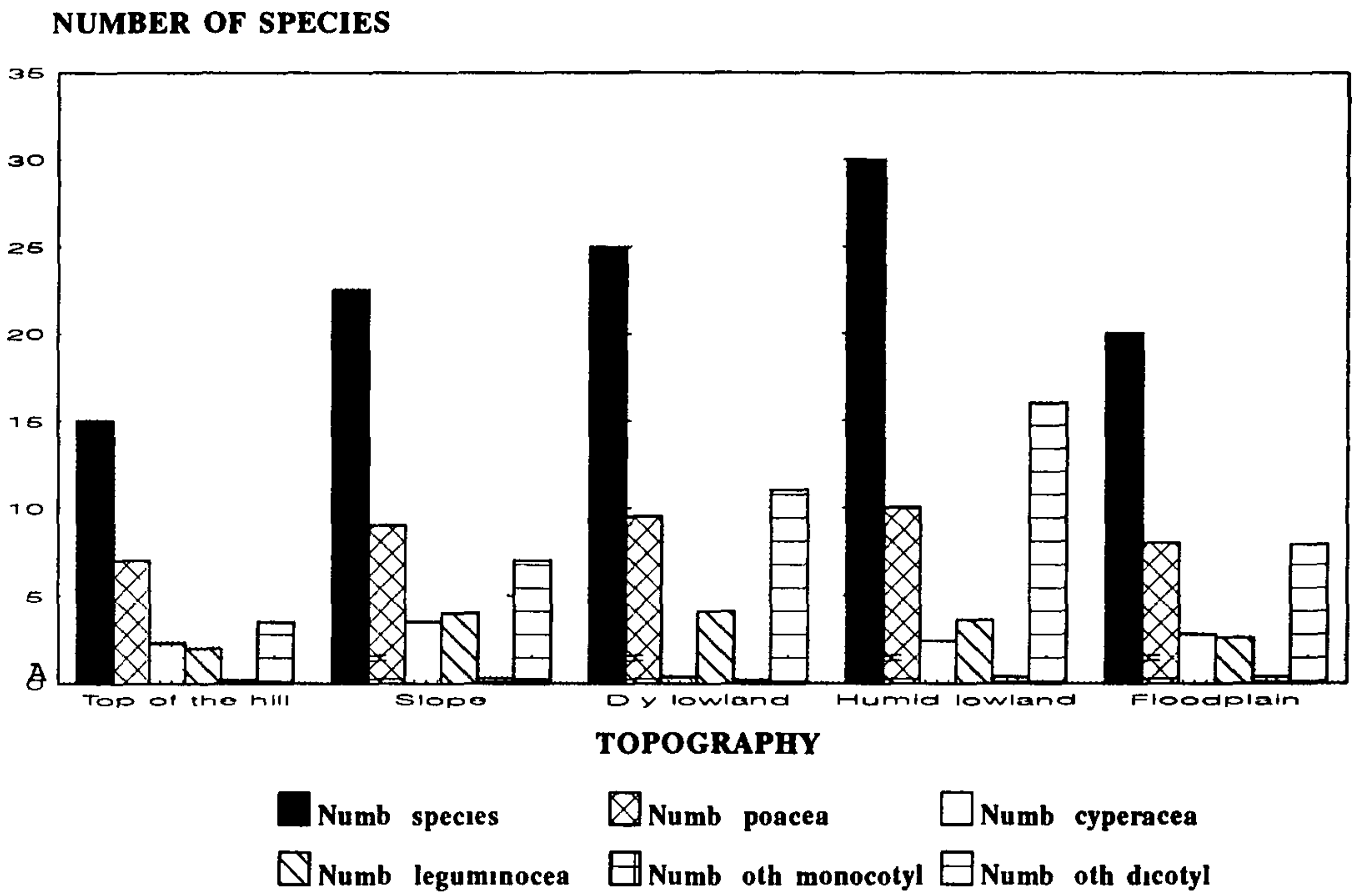


Figure 7 Vegetation of serrania Topography and number of species

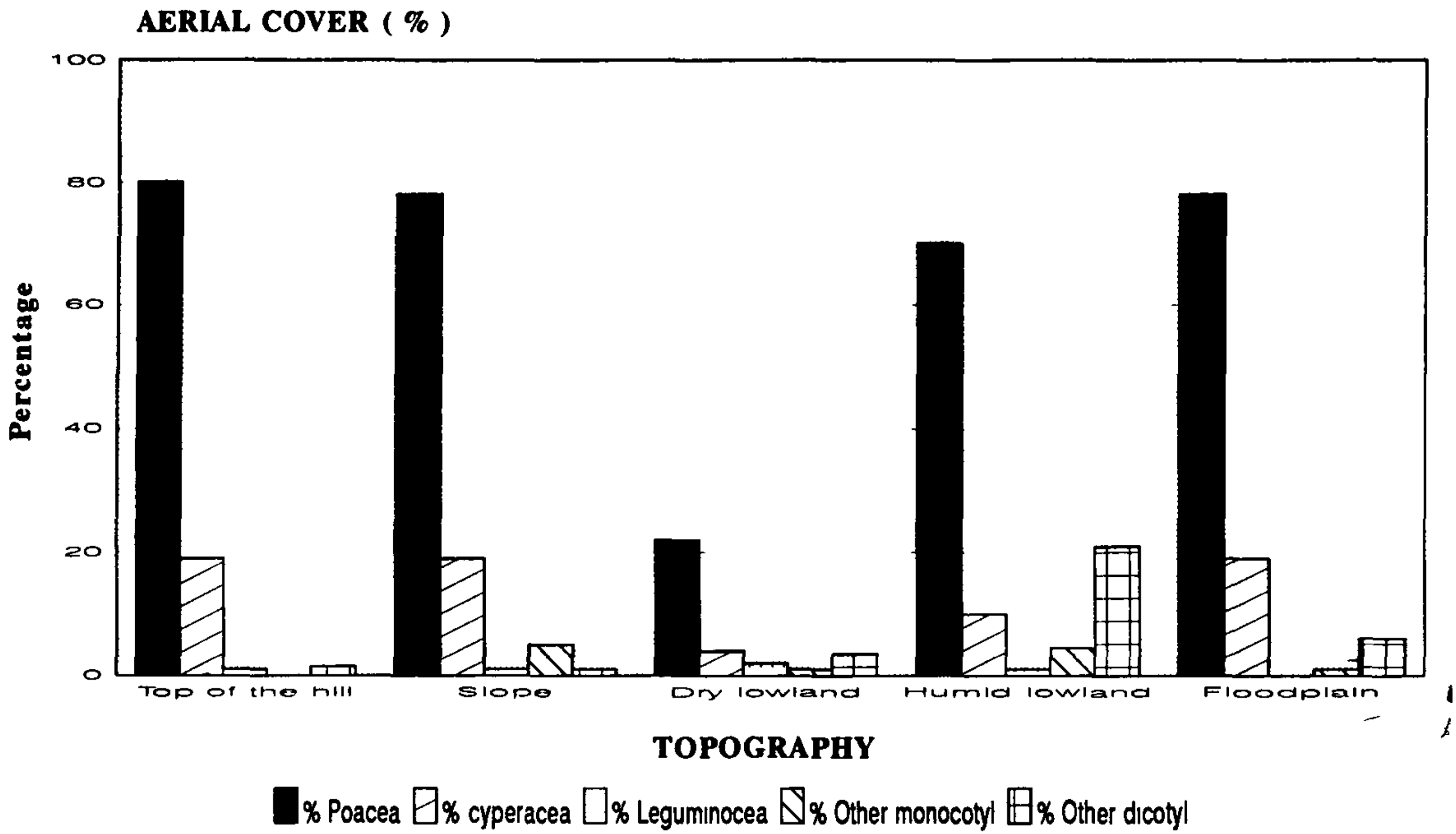


Figure 8 Vegetation of serrania Topography and relative aerial cover by herbaceous plants

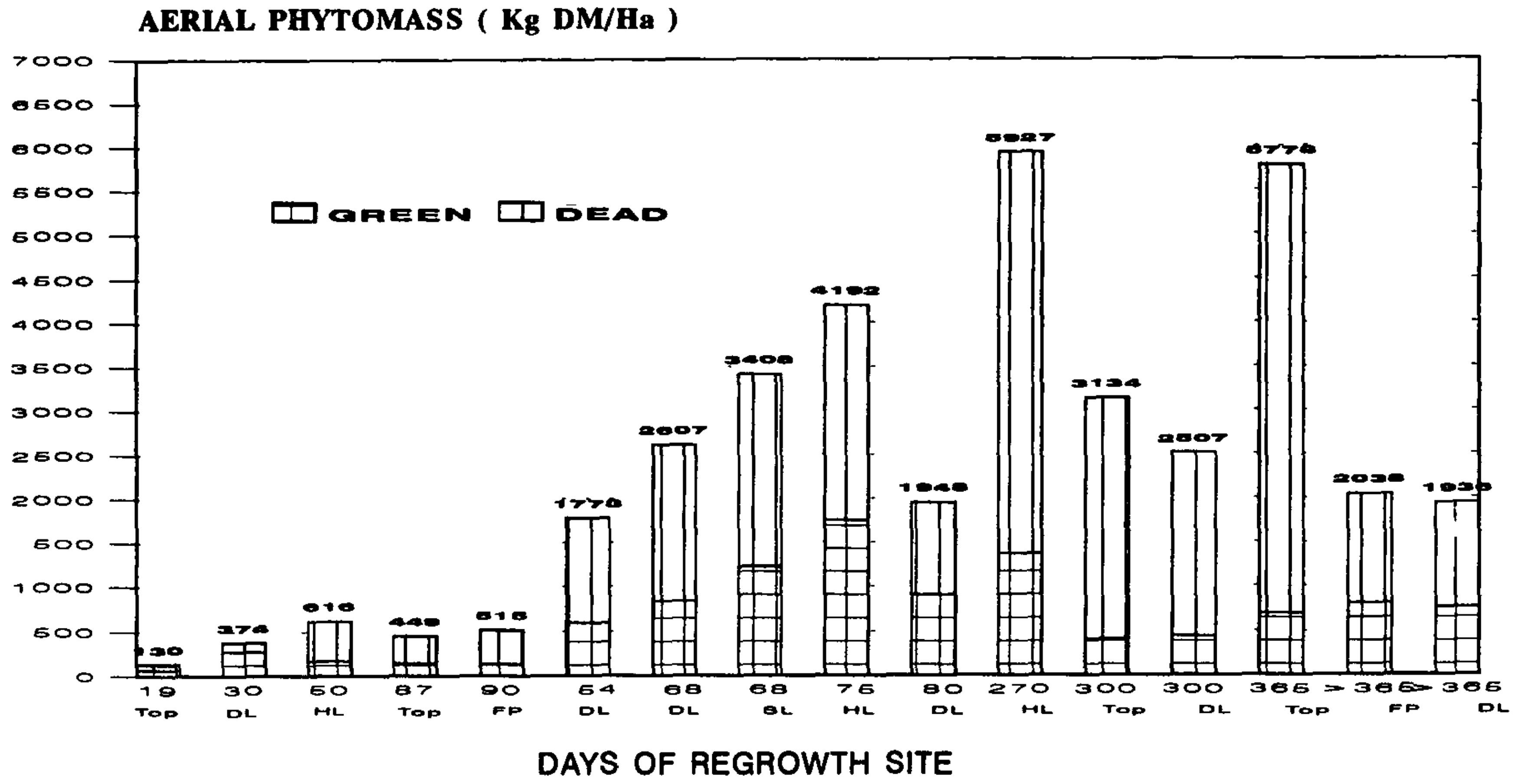


Figure 9 Aerial phytomass from different native pasture after burning

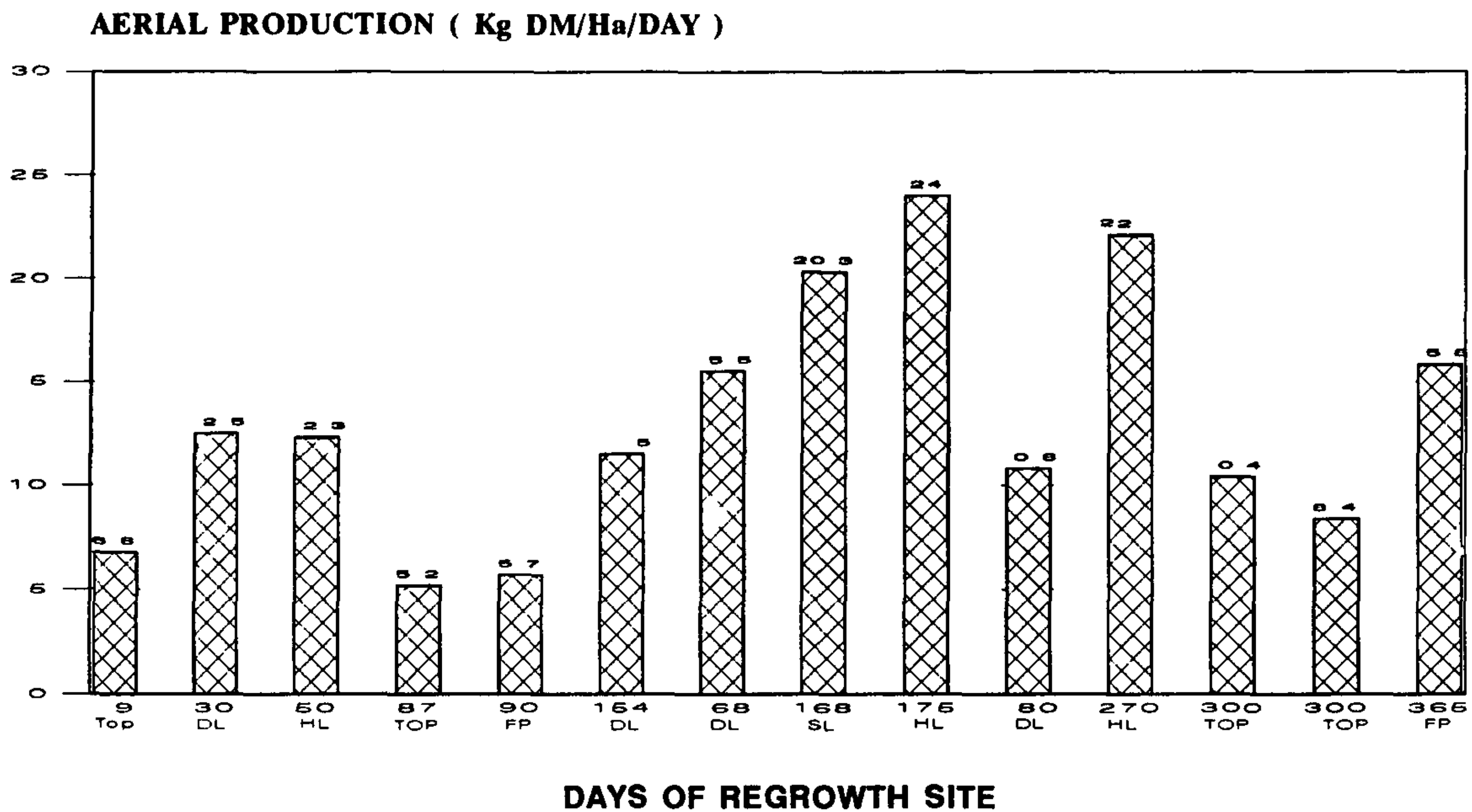


Figure 10 Aerial production from different native pasture after burning

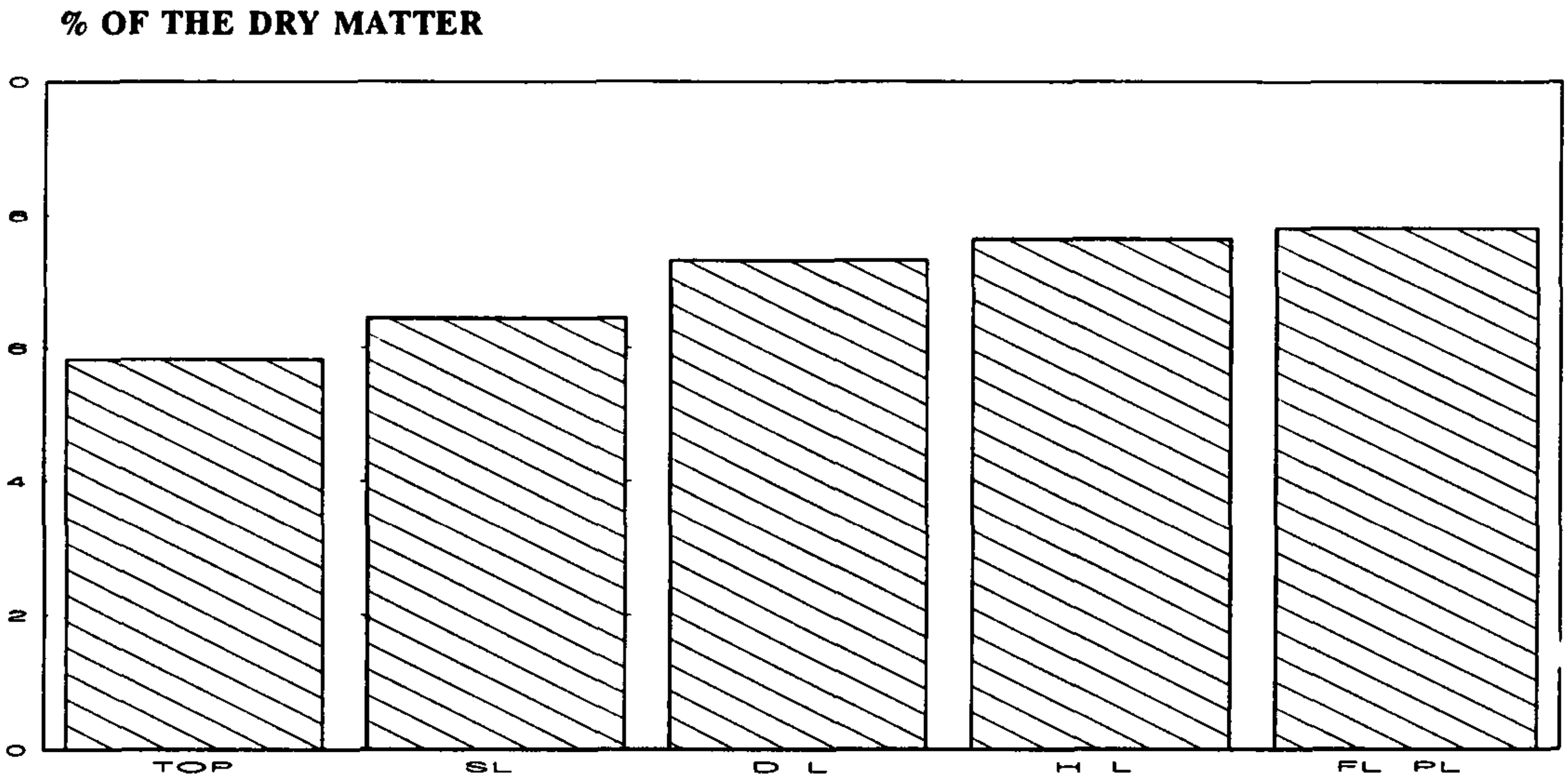


Figure 11 Protein content in the pasture related to the different topographic sites

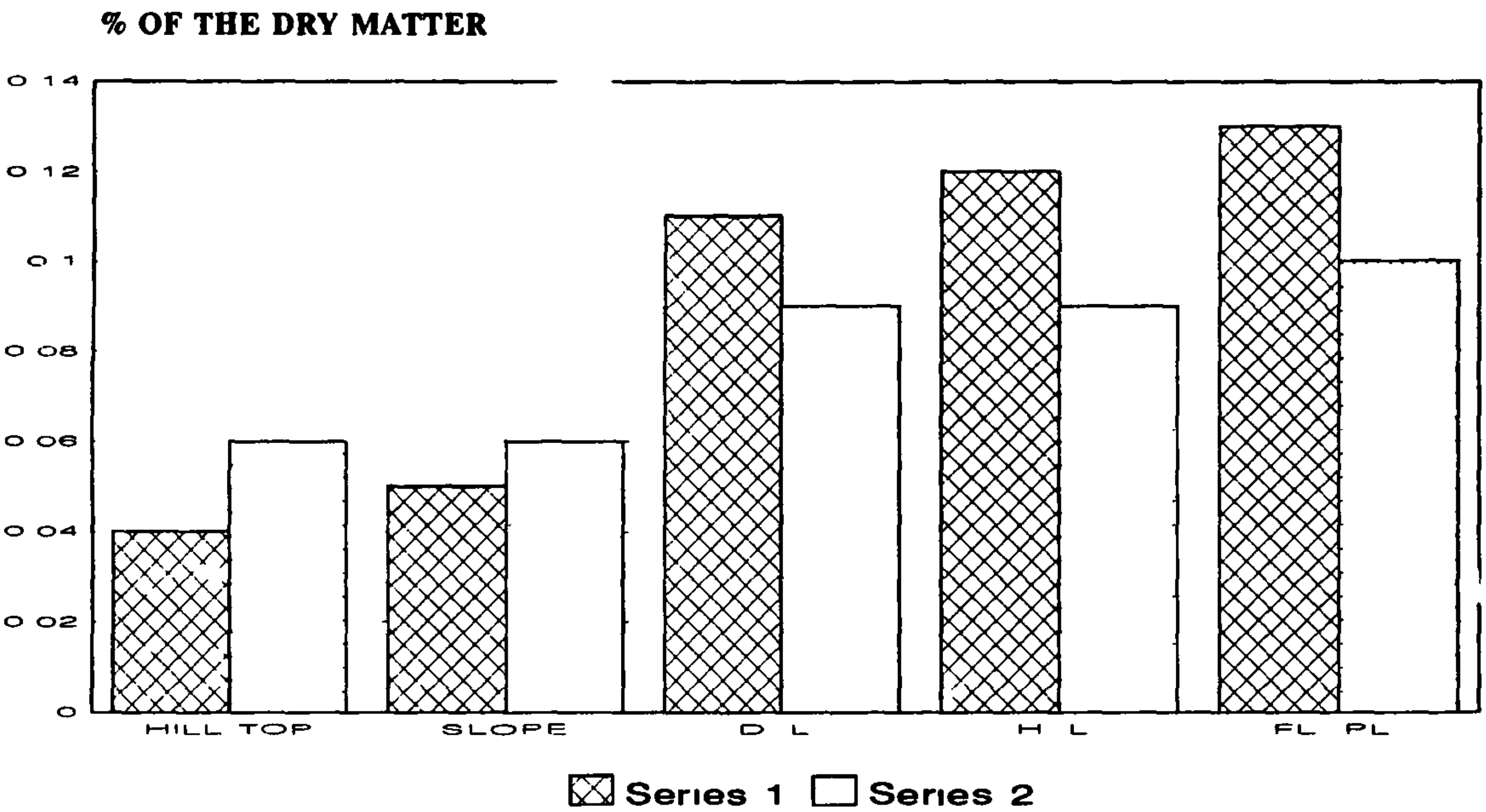


Figure 12 P and Ca content in the pasture related to the different topographic sites

3 9 Soil texture

Figure 13 shows that the sandy clay loam structure dominates at the top of the hills and slopes and in the dry lowlands In the humid lowlands and the floodplain a clay loam or a loam structure dominates

3 10 Chemical soil analysis

The percentage organic material (Figure 14) is the lowest at the top of the hills (2 0%) and the highest in the humid lowlands (12 2%) It increases slightly from the top of the hills to the dry lowlands It shows a strong increase from the dry lowlands to the humid lowlands and a slight decrease to the floodplain

In Figure 15 the C/N ratio from the different sites is given It shows that the C/N ratios in the soil are very high even on the top and the slopes They fluctuate between 18 and 24

The Ca content is lowest at the top of the hills (0 11 milliequivalent/100 gr soil) and highest at the slopes (0 14 milliequivalent/100 gr soil) The concentration of Mg and K follow the same pattern They are lowest at the top of the hills (0 04 milliequivalent/100 gr soil and 0 05 milliequivalent K/100 gr soil) and highest in the humid lowlands (0 00 milliequivalent/100 gr soil and 0 10 milliequivalent K/100 gr soil) (Figure 16)

The Al concentration is lowest at the top of the hills 0 62 milliequivalent/100 gr soil and is increasing to 3 42 milliequivalent/100 gr soil for the humid lowlands Afterwards it is decreasing to 2 22 milliequivalent/100 gr soil for the floodplains (Figure 17)

4 CONCLUSIONS

It is possible to conclude that there are differences in the composition of the vegetation related to differences in relief soil type and hydrology to some extent

Four different plant communities were identified (at this stage of the work) which show a relation with the topography Two community types are identified for the top of the hills and slopes For the first community five characteristic species could be identified of which the grasses *Trachypogon vestitus* and *Paspalum pectinatum* are the most typical In the second community five characteristic species are also identified of which the grass *Trachypogon plumosus* is the most typical Two community types are identified for the humid lowlands and floodplains There are six characteristic species identified for this community of which the grass *Andropogon selloanus* can be classified as most typical For the last community 13 characteristic species could be identified of which the grasses *Andropogon bicornis* and *Schizachyrium brevifolium* could be classified as most typical

Differences in aerial cover relative aerial cover and average number of species between the topographic units are to some extent due to differences in soil properties and soil texture

It is shown that the nutrient supplies in the humid lowlands and floodplains are somewhat better than at the top of the hills slopes or in the dry lowlands It seems that the nutrient supplies are best in the humid lowlands except for Ca and P This last element may be fixed by aluminium whose percentage is highest in the humid lowlands The great number of different species in the humid lowlands can to some extent be explained by a high moisture percentage a higher percentage of organic material and a higher nutrient supply

The data of this research show a great difference in aerial biomass among the topographic sites

A very low percentage of green matter after 30 days of regrowth was observed The aerial production is much higher in the lowland for short regrowth periods For longer periods it is difficult to conclude because of more intensive grazing in the lowlands Figures 9 and 10 not only show us a very high production for the humid lowland but also for the top of some hills

The differences in forage value among the topographic units are very small The data of the chemical plant analyses show a low nutritive value for the Serranía pastures The average percentage P is even lower than the critical value necessary for good animal performance The figures for nitrogen content are not much better When the nutritive value of the different topographic sites are compared it is shown that the situation is slightly better in the floodplains However it is also impossible to draw conclusions from these data because differences in age and stage of the plant material were neglected when the chemical analyses were made To come to a further differentiation and classification of the Serranía vegetation and ecology it is necessary to continue research More samples should be taken and a system has to be made in this sample recording

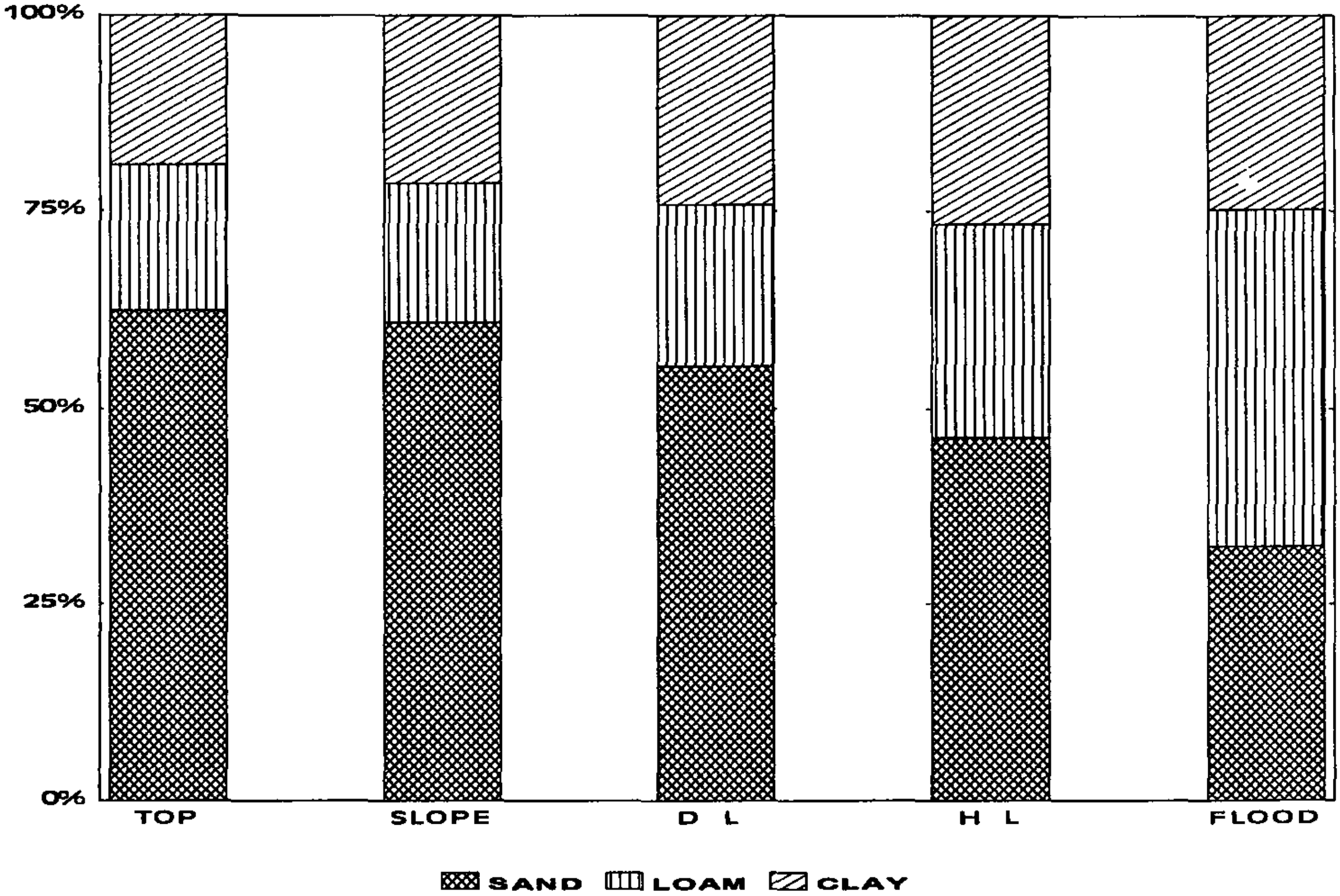


Figure 13 Soil texture related to different topographic sites

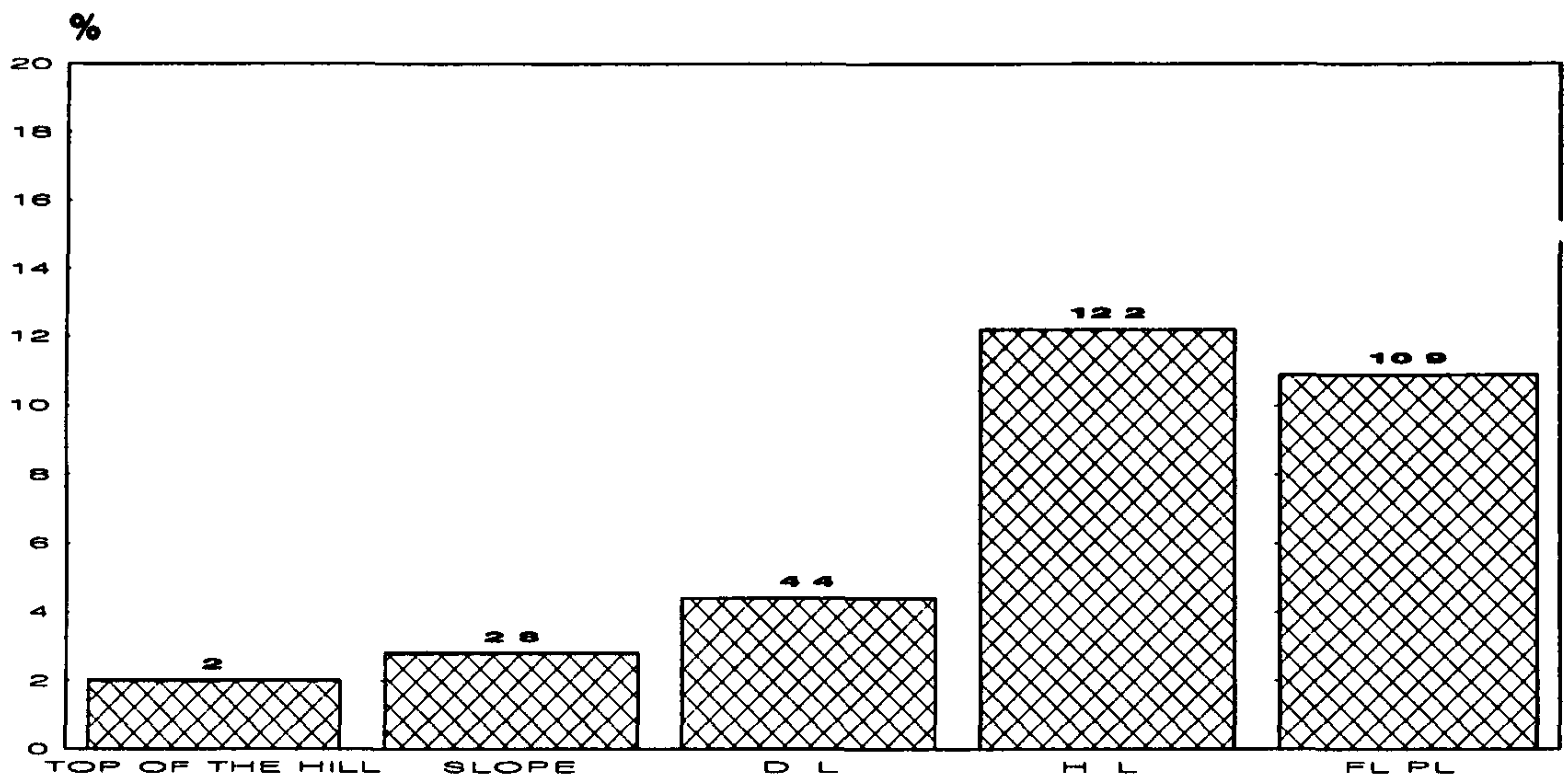


Figure 14 Organic material in the soil

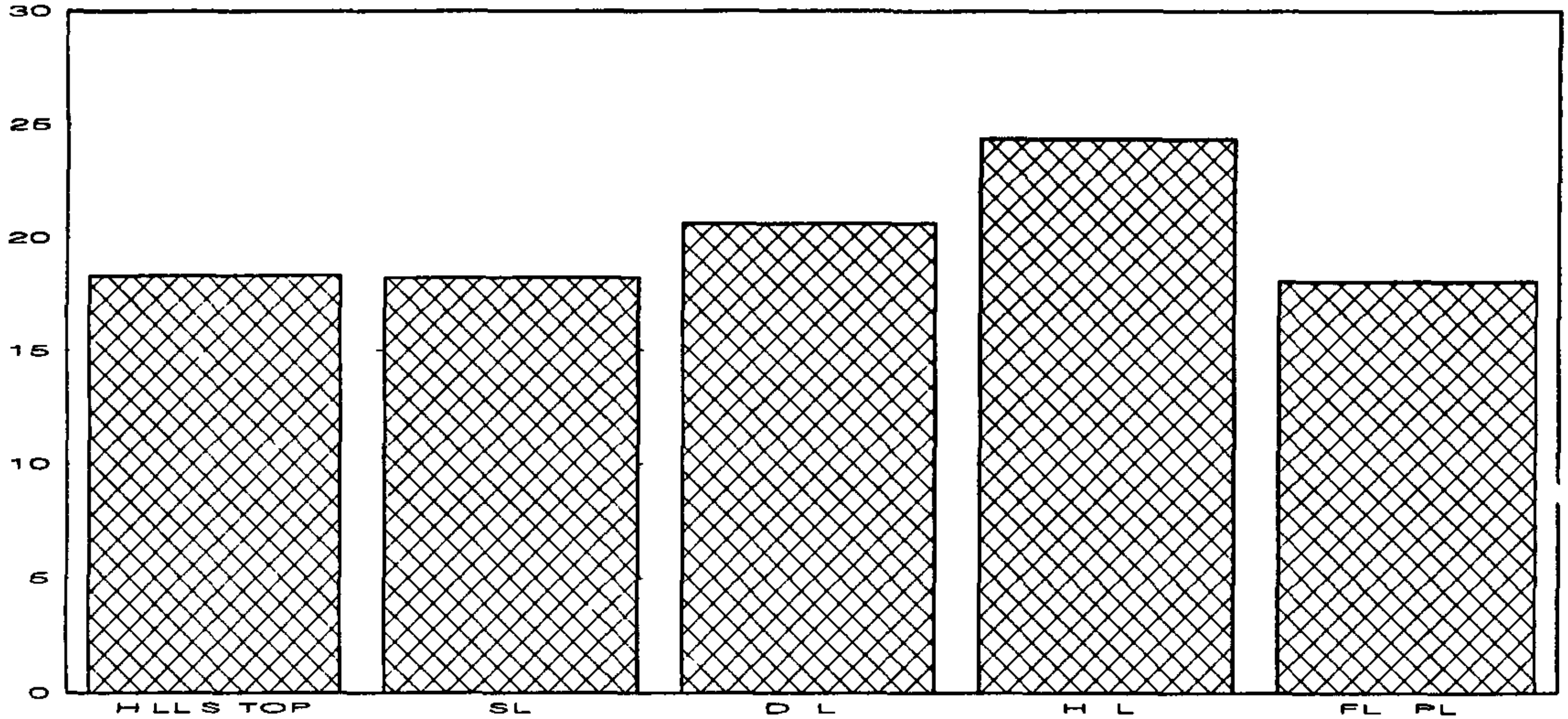


Figure 15 Ratio C/N in the soil

MACRONUTRIENT (Meq / 100 soil)

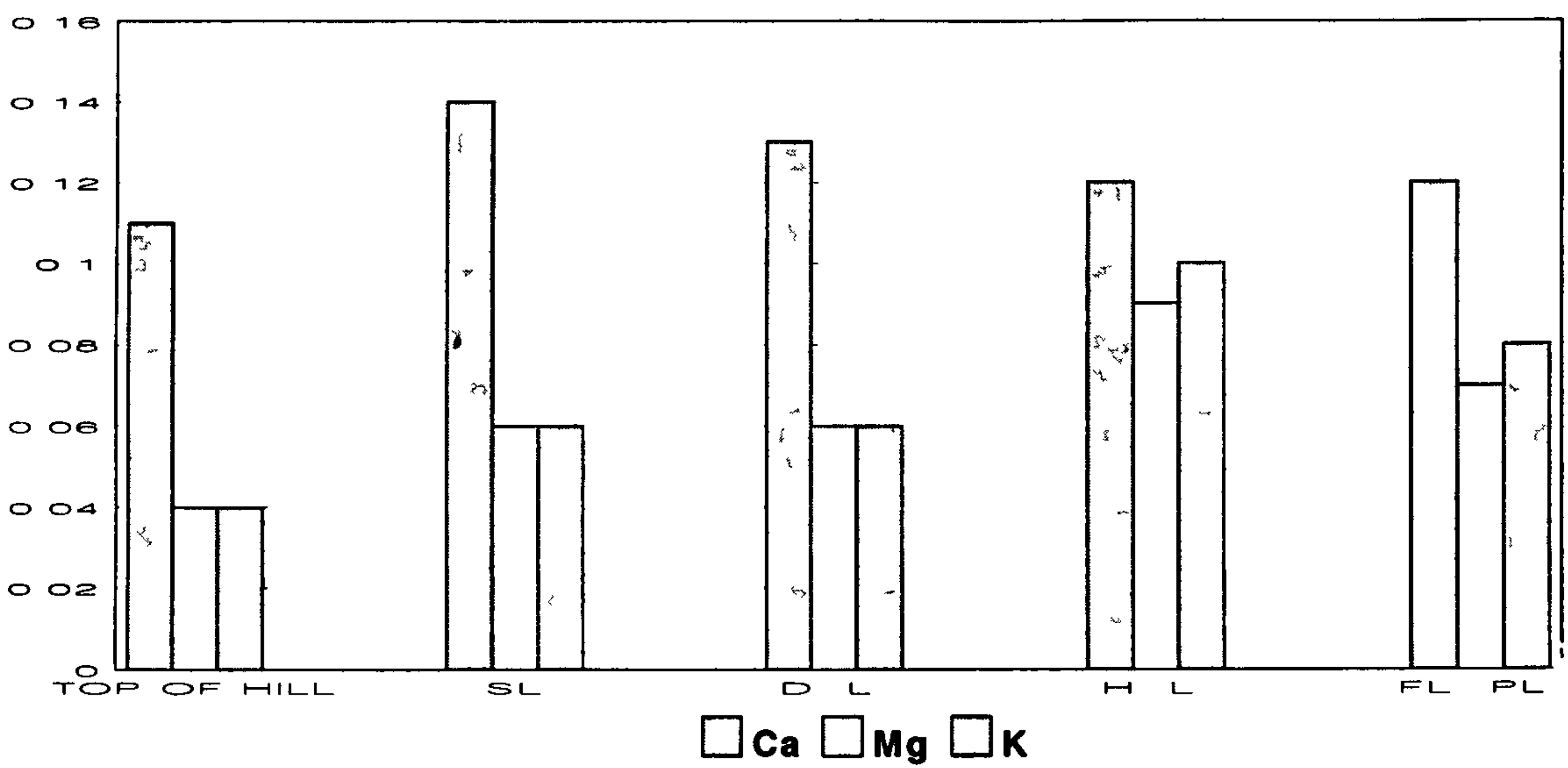


Figure 16 Concentration of Ca, Mq and K in the soil related to the different topographic sites (Meq / 100g soil)

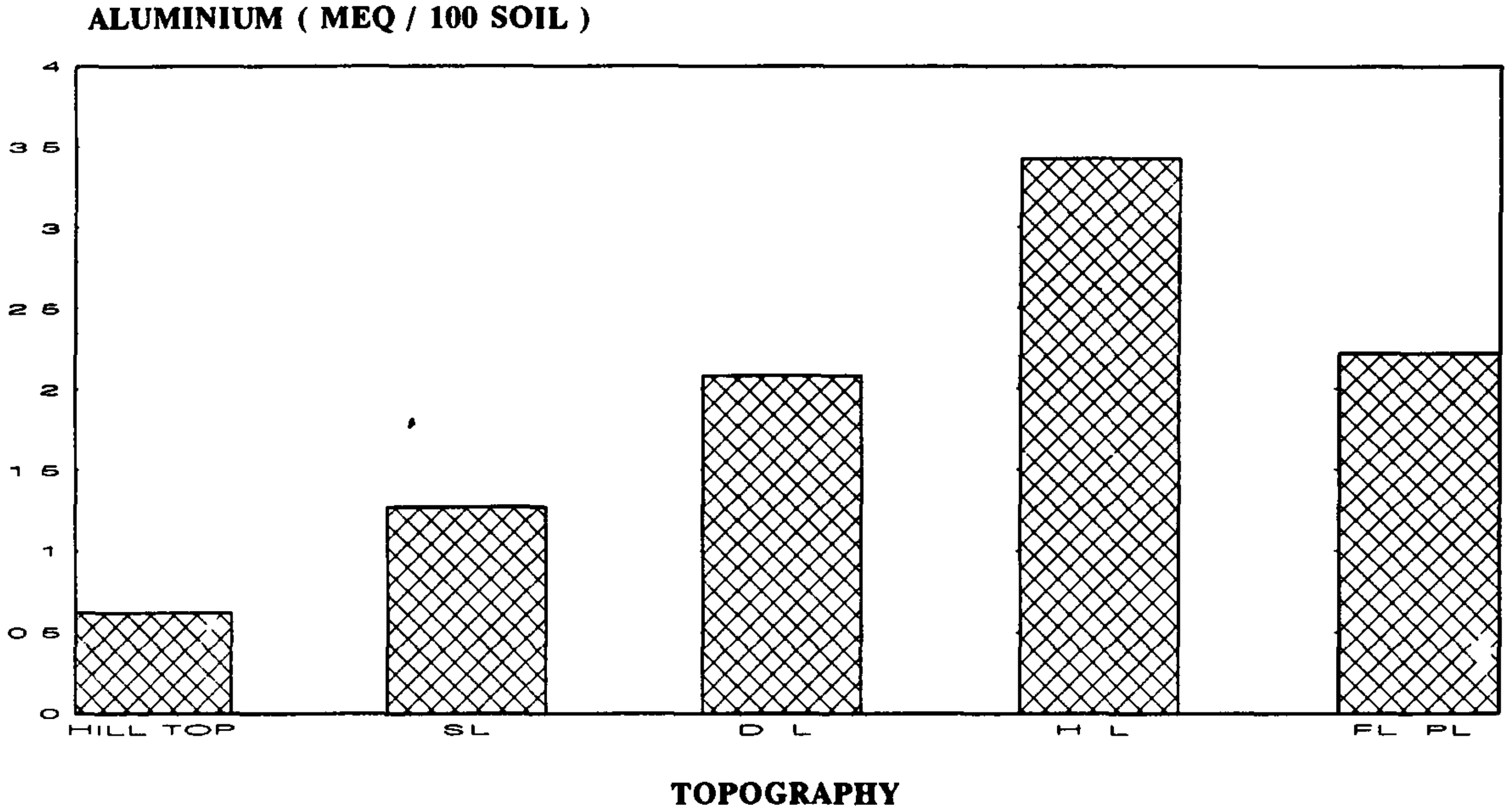


Figure 17 Aluminium concentration in the soil related to the different topographic sites (Meq / 100 soil)

ANNEX 1
PLANT FAMILIES AND SPECIES FROM THE SERRANIA NATIVE PASTURES

	FAMILIES	SPECIES
1	ACANTHACEAE	*Ruell a gem n flora*
2	AMARANTHACEAE	*Alte n nthera* sp
3	AMARYLLIDACEAE	*Curcul go scorzoneraefolia*
4	ANNONACEAE	*Xylop a* sp
5	ARACEAE	*Calad um macrotiles*
6	ARISTOLOCHIACEAE	*Aristoloch a nummularifolia*
7	CAESALPINIACEAE	*Chamaecrista* sp
8		*Chamaecr sta cultr fol a*
9		*Chamaecrista desvauxii*
10		*Chamaecris ta d sphylla*
11		*Chamaecrista hisp dula*
12		*Chamaec sta kunth ana*
13		*Chamaec sta rotund folia*
14	COMPOSITAE	*Calea colomb ana*
15		*Composite* sp
16		*Eupatorium* sp
17		*Eupator um amygdal num*
18		*Ichthyothere term nalis*
19		*St lpnopappus p ttieri*
20	CONVOLVULACEAE	*Ipomea f stulosa*
21		*Merremia aterensis*
22	CYPERACEAE	?
23		*Bulbostyl s paradoxa*
24		*Cyperus bre fol us*
25		*Cyperus flavecens*
26		*Cyperus flavus*
27		*D ch omen c l ata*
28		*Rhynchospora ba bata*
29		*Rhynchospora conf nis*
30		*Rhynchospo a corymbosa*
31		*Rhynchospo a globosa*
32		*Rhynchospora podeosperma*
33		*Rhynchospora pubera*
34		*Rhyn hospora subplumosa*
35		*Scler a d stans*
36	DILLENIACEAE	*Curatella americana*
37	ERISTOLACEAE	*Eryth oxylum* sp
38	EUPHORBIACEAE	*Croton tr nitat s*
39		*Euphorbia commun s*
40		*Eupho b a hirta*
41		*Phyllanthus* sp
42		*Phyllanthus n u*
43	FABACEAE	*Centrosema angust folium*
44		*C nt osema enosum*
45		*Cl to* sp
46		*Clitoria guianensis*
47		*Crotalari* p
48		*C otala n t dula*
49		*Desmod um barbatum*
50		*Eriosema* sp
51		*Eriosema cr n tum*
52		*Eriosema rufum*
53		*Eriosema s mplicifol um*
54		*Galactia glaucescens*
55		*Galactia juss aeana*
56		*Indigofe a lespedez o des*
57		*Macropt l um monophyllum*
58		*Stylosanthes guianens s*
59		*Vigna l near s*
60		*Zo n a* sp
61	FLACVORTIACEAE	*Casearia syl estris*
62		*Casear a ulmifol a*
63	GENTIANACEAE	*Irlbach a alata* subsp *alata*
64		*Schultesia* sp
65	GUTTIFERAE	*V sm a dealbata*
66	HAEMODORACEAE	*Schiekia o nocens s*
67	IRIDACEAE	*Cypella l nearis*
68	LABIATAE	*Hyptis* sp
69		*Hyptis atrorubens*
70		*Hyptis brach ata*
71		*Hyptis capitata*
72		*Hyptis conferta*
73		*Hyptis dilatata*
74		*Hyptis verticillata*
75	LYTHRACEAE	*Cuphea calophylla*
76	MALPIGHIACEAE	*Byrson ma* sp
77		*By son ma crass fol a*
78		*Byrson ma ve basc folia*
79	MALVACEAE	*Pa on a* sp
80		*Peltaea spec osa*
81		*S da acuta*
82		*S da l nifolia*
83	MELASTOMATACEAE	*Cl dem a ubra*
84		*Desmocellis llosa*
85		*Micon a* sp
86		*Micon a rubiginosa*
87		*Micon a rufescens*
88		*Pterogastra mayor*
89		*Tococa guianens s*
90	MENISPERMEACEAE	*C ss mpelos oval fol a*
91	MIMOSACEAE	*M mosa pud ca*
92	MYRTHACEAE	*Myrc a guianen s*
93		*Psid um* sp
94		*Ps d um ma bense*
95		*Ps d um salut*
96	OCHNACEAE	*Sauv ges a e ecta*
97	ONAGRACEAE	*Ludw g a decu ens*
98	PALMAE	*Maurit a m no*
99	PASSIFLORACEAE	*Pass flora foet da*
100	POACEAE	?
101	POACEAE	*And opogon* sp
102		*And opogon b co n s*
103		*Andropogon gayanus*

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

ANNEX 2 SYNOPTIC TABLE (BRAUN – BLANQUET METHOD)

No SAMPLE (RELEVE)		11	10	12	1	15	17	4	30	14	20	22	25	5	23	21	27	9	28	7	19	24	13	16	31	26	18	2	6	3	8	29
TOPOGRAPHIC SITE		s	t	t	t	d	s	d	d	d	d	s	d	t	s	t	t	t	s	d	h	f	h	d	h	f	h	h	d	h	f	f
		l	p	p	p	l	l	l	l	l	l	l	l	p	l	p	p	p	l	l	l	p	l	l	l	p	l	l	l	l	p	p
GEOGRAPHIC SITE		p	p	p	p	p	p	p	p	p	s	s	s	p	s	s	p	p	p	p	s	s	p	p	p	p	p	p	p	p	p	p
		g	g	g	g	g	g	g	l	g	l	l	l	g	l	l	l	g	l	g	l	l	g	g	l	l	g	g	g	g	g	l
		2	2	2	1	2	2	1	0	2	t	t	t	1	t	t	0	1	0	1	t	t	2	2	0	0	2	1	1	1	1	0
SPECIES No		ABUNDANCY DOMINANCY																														
		TOP – SL							DRY LOWLAND												LOWLANDS											
11	Chama his	3	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	Rhync pub	3	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	Erios sp	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
153	Trach ves	4	3	4	4	5	5	4	-	3	2	-	-	-	-	-	-	-	4	3	-	-	-	4	1	-	-	-	1	-	-	-
142	Paspa pec	-	3	1	3	3	3	3	-	-	4	4	1	3	1	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-
148	Schiz hir	2	3	-	3	3	-	-	2	-	-	-	-	-	-	-	-	-	4	-	-	-	1	-	-	-	2	-	3	-	-	-
120	Cteni pla	-	1	-	-	-	-	4	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
137	Paspa cot	3	-	-	-	-	4	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
160	Sperm sp	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
21	Merre ate	-	1	-	-	-	3	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
170	Turne ul	-	-	-	-	-	2	1	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	1	-	-
46	Clito gui	1	1	-	-	3	-	-	-	1	-	1	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
55	Galac jus	1	1	1	-	1	1	1	-	3	1	1	-	3	3	1	-	-	1	2	-	-	-	1	-	-	-	-	-	-	-	-
23	Bulbo par	4	3	4	-	-	3	-	-	-	-	4	2	3	3	4	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
78	Byrso ver	1	1	1	-	-	1	-	-	1	-	-	-	1	1	1	-	1	-	-	-	-	-	-	1	-	-	-	-	1	-	-
154	Polyg pan	1	1	1	-	-	-	-	-	-	1	1	1	-	-	-	1	-	1	3	-	-	-	-	-	-	-	-	-	-	-	-
156	Decli fru	-	-	1	2	1	-	2	1	-	-	-	1	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
18	Ichth ter	-	-	-	-	-	1	-	-	-	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
128	Mesos pit	-	4	3	4	-	-	-	6	4	5	4	4	-	5	4	4	-	4	-	-	-	-	4	-	4	-	-	-	-	-	-
152	Trach plu	3	-	-	-	-	-	6	-	3	5	4	5	5	4	5	4	-	-	-	-	4	-	4	4	-	-	-	1	-	-	-
31	Rhync glo	-	-	-	3	-	-	-	-	-	3	-	-	4	1	4	1	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
54	Galac gla	-	-	-	-	-	-	-	-	-	1	1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
155	Borre cap	-	-	-	-	-	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
100	Grami –??	-	-	-	-	-	-	-	-	-	2	-	2	-	-	2	4	5	3	-	5	4	-	-	2	-	-	3	-	-	-	-
77	Byrso cra	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-
1	Ruell gem	-	-	1	-	3	-	-	-	1	-	-	-	-	-	-	-	-	-	3	-	-	1	-	-	-	-	-	-	-	-	-
127	lepto lan	1	-	-	4	3	5	3	-	-	3	3	4	4	-	-	-	-	-	3	4	4	4	3	3	1	3	-	-	-	-	-
53	Erios sim	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	1	2	3	3	-	1	-	-	-	-	-	-
27	Dichr cil	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	4	-	-	1	4	-	-	2	-	-	-	-	-
106	Andro sel	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	1	4	4	-	-	-	-	-	-	6	-
7	Chama –sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	-	-	-	-	-	-	-	-	-	-	-
87	Micon ruf	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-	1	-	-	1	-	-	-
133	Paspa –sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	3	3	-	-	-	-	-	-	-	-	1	-
57	Macro mon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-	1	-	1	2	-	-
68	Hypti –sp	-	-	-	-	-	-	-	-	3	2	-	-	-	-	-	-	-	-	-	1	-	1	1	4	3	-	-	-	-	-	-
69	Hypti atr	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	1	1	-	-	1	-	3	-	2	-	-	-	-

ANNEX 2 (CONTINUED)

No SAMPLE (RELEVE)		11	10	12	1	15	17	4	30	14	20	22	25	5	23	21	27	9	28	7	19	24	13	16	31	26	18	2	6	3	8	29
TOPOGRAPHIC SITE		sl	tp	tp	tp	dl	sl	dl	dl	dl	dl	sl	dl	tp	sl	tp	tp	tp	sl	dl	hl	fp	hl	dl	hl	fp	hl	hl	dl	hl	fp	fp
GEOGRAPHIC SITE		pg2	pg2	pg2	pg1	pg2	pg2	pg1	pl0	pg2	slt	slt	slt	pg1	slt	slt	pl0	pg1	pl0	pg1	slt	slt	pg2	pg2	pl0	pl0	pg2	pg1	pg1	pg1	pg1	pl0
SPECIES No		ABUNDANCY DOMINANCY																							FLOODPLAIN							
36	Curat ame	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	1	4	-	1	-	-	1	-	-	-	-
14	Calea col	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	-	-	1	-	-	-	-	-
169	Turne pum	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	1	-	-	-	-
72	Hypti con	-	-	-	3	-	-	1	-	-	-	-	-	-	-	-	-	-	-	2	3	2	1	-	1	3	3	3	1	2	-	-
88	Ptero may	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	1	1	-	-	1	-	1	-	-	1	-	-
158	Sabic vil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	1	1	-	4	3	2	-	-
83	Clide rub	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	2	-	-	-	-	-
104	Andro hyp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	1	-	3	-	-	-
126	Hypog vir	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	1	3	-	-	-	-	-	-
132	Panic ste	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	4	-	5
159	Sipan pra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-
173	Xyris c-m	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	4	-	-	-	-
75	Cupe cal	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	1	-	3	4	4	4	-	-	-	1
163	Linde dif	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	3	-	1	-	-	3	3	3	1	2	-	-	-
147	Schiz bre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	3	4	3	-	3	-	-
102	Andro bic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	3	-	-	1	-	-	4
165	Bittn mol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1	-	-	-	3	3
30	Rhync cor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	3
38	Croto tri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	-	-
74	Hypti ver	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-
84	Desmo vil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	1	-	-
91	Mimos pud	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-	-
97	Ludwi dec	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	3	-	-
124	Gymno fas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	4	-	-	-	-
96	Sauva ere	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	3	-	1	2	-	2	-	-
25	Cyper fin	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-
107	Andro vir	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	4	-	-	3	-	-	-
129	Otach ver	-	-	-	-	-	-	-	-	1	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	4	4	-	3	-	-	-
52	Erios ruf	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	1	-	-	-	-	-	3	1	-	-	-	-	-	-
8	Chama cul	1	-	-	-	1	1	-	-	-	-	-	-	3	-	-	-	-	1	-	-	-	-	-	-	1	1	-	-	-	-	-
42	Phyll nir	1	-	-	3	-	-	1	-	1	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	1
49	Desmo bar	-	-	-	2	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-
172	Xyris car	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	1	-	-	-	-	-	3
108	Arist cap	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	5	-	-	-
149	Setar gen	-	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-
150	Thras pet	-	-	-	-	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
59	Vigna lin	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-
61	Casea syl	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
105	Andro leu	4	6	4	5	4	4	4	5	5	-	1	-	-	-	-	-	3	-	4	4	3	4	-	-	4	4	-	1	5	-	-
135	Paspa car	5	3	5	5	5	-	-	-	-	4	2	5	2	4	4	6	5	4	3	-	4	4	-	4	4	-	-	-	-	-	-
29	Rhync con	1	3	-	-	3	1	-	4	-	-	2	-	5	4	3	1	-	4	-	4	-	-	-	4	1	1	-	-	-	3	5
101	Andro -sp	-	-	-	3	-	3	3	-	1	-	-	-	3	-	-	2	5	-	-	-	-	1	-	-	-	4	5	-	-	-	-
51	Erios cri	-	1	-	-	1	1	-	1	-	1	-	-	1	-	-	-	-	-	-	-	-	1	1	-	-	-	-	1	-	-	-
70	Hypti bra	-	-	-	-	1	1	-	-	1	1	1	-	1	-	-	-	-	-	-	1	-	1	-	-	-	-	-	2	1	-	-
73	Hypti dil	-	-	-	-	4	-	1	1	-	-	-	1	-	-	-	-	-	1	1	-	-	-	-	-	-	-	3	3	1	-	-
117	Axono pur	-	-	-	2	-	-	-	3	5	-	-	2	-	-	-	-	-	-	-	4	-	-	3	-	3	-	-	5	-	3	-

ANNEX 2 (CONTINUED)

No SAMPLE (RELEVE)		11	10	12	1	15	17	4	30	14	20	22	25	5	23	21	27	9	28	7	19	24	13	16	31	26	18	2	6	3	8	29
TOPOGRAPHIC SITE		sl	tp	tp	tp	dl	sl	dl	dl	dl	dl	sl	dl	tp	sl	tp	tp	tp	sl	dl	hl	fp	hl	dl	hl	fp	hl	hl	dl	hl	fp	fp
GEOGRAPHIC SITE		pg2	pg2	pg2	pg1	pg2	pg2	pg1	pl0	pg2	slt	slt	slt	pg1	slt	slt	pl0	pg1	pl0	pg1	slt	slt	pg2	pg2	pl0	pl0	pg2	pg1	pg1	pg1	pg1	pl0
SPECIES No		ABUNDANCY DOMINANCY																														
62	Casea ulm	-	-	-	-	1	-	1	-	-	2	1	-	1	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-
161	Sperm cap	-	1	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	1	-	-	-	-	1	1	2	-	-	-	-
22	Cyper -??	-	-	-	-	-	-	4	-	-	-	3	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	4	4	-
114	Axono anc	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	-	1	-	-	-	-	-
112	Axono -sp	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	2	-	-	-	1	-
17	Eupat amy	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	2	-	-
138	Paspa cov	-	-	-	-	-	-	4	-	-	-	-	-	-	4	3	-	-	-	-	-	5	-	-	-	-	-	-	-	2	-	-
63	Irlba a-a	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-
136	Paspa cla	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	1	-	-	-	-	3	-	-	-	-	-	-
47	Croto -sp	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	3	-	-	-	-
95	Psidi sal	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
2	Alter -sp	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
64	Schul -sp	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
67	Cypel lin	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
93	Psidi -sp	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
94	Psidi mar	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
110	Arist ter	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
115	Axono aur	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
141	Paspa par	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	Rhync bar	3	-	-	-	-	-	-	-	-	-	4	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Curcu sco	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Chama kun	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	Compo -sp	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	Rhync sub	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	Centr ang	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	Clito -sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
48	Crota nit	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
58	Stylo gui	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60	Zorni -sp	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
80	Pelta spe	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90	Cissa ova	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
121	Digit nee	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
145	Sacci myu	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
146	Schiz -sp	-	-	-	-	-	-	-	-	-	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
157	Sabic col	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
171	Xyris -sp	-	-	-	-	-	-	-	-	-	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
92	Myrci gui	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
19	Stilnp pit	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
76	Byrso -sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
131	Panic par	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
166	Meloc col	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
6	Arist num	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
44	Centr ven	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
71	Hypti cap	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
81	Sidaa cut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
82	Sidal ini	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-

Subproject TL 03 2 native pasture management a sequential burning and rotational grazing of the native pastures of the flat plain (Altillanura) of the Llanos *G Rippstein (CIAT/CIRAD EMVT) A G E Peters (U Wageningen) J K Broekhuijsen (U Wageningen) G Escobar (TL)*

1 INTRODUCTION

The Llanos of Colombia consists of an area of 17 million hectares covered with tropical savanna Extensive cattle production is practiced in this area because of lack of nutritive forage during the dry season of the year The fluctuations in quantity of nutritive forage between wet and dry season cause fluctuations in liveweight gain for animals grazing here resulting in very low production figures of 28 kg/an/year at a stocking rate of 0 2 an/ha With the lack of infrastructure in this area the importance of production improvement by low external inputs becomes clear A possibility for this lies in adjusted management systems Factors within this are burning and grazing A lot of investigation has been done on burning systems and grazing systems indicating degradation of the pasture or small increases in animal production under these treatments Therefore a management systems of sequential burning resulting in regrowth every month combined with rotational grazing was proposed This systems was studied for its effect on the vegetation dynamic and the development of weight of grazing animals at two stocking rate during three months at Carimagua the research Center of CIAT/CORPOICA

2 MATERIALS AND METHODS

Before burning the vegetation of the plots was one year old consisting of annuals and perennials Soil was totally covered by a dry biomass dominated by the dormant perennials *Trachypogon vestitus* and *Axonopus purpusii* These would start their germination at the start of the wet season or after a fire at the end of the dry season Annuals were present mainly as seeds in the seed bank because of unfavorable environmental conditions for growth Some of these would germinate either when growth conditions improve (e g increase in water availability decrease in competition for growth factors) or by photoperiodical control after occurrence of the longest days in June July

For the study of the vegetation dynamics and evolution of animal weight gain in the proposed management system there are 8 research questions to investigate These are concerned with the effect of

1 Period of burning on the botanical composition of the vegetation
2 Stocking rate (SR) on the botanical composition of the vegetation
3 Period of burning on the production of the vegetation
4 Stocking rate on the production of the vegetation
5 Period of burning on the development of the weight of grazing animals
6 Stocking rate on the development of the weight of grazing animals
7 Period of burning on the diet preference of the animal
8 Stocking rate on the diet preference of the animals

The research was performed on native savanna on clay soil with pH (H_2O) of 4 9 and organic matter content of 3 1% in the upper 20 cm of the soil The amounts of exchangeable cations calcium magnesium potassium and aluminium of this soil are 0 19 0 073 0 064 and 0 2 Meq/100 g respectively Aluminium saturation is very high 82% Due to this high aluminium availability the availability of phosphorus was low 0 9 ppm (CIAT 1990 and Tergas 1986) Media annual rainfall is 2200 mm and average temperature is 26 degrees Celsius (Table 18)

Table 18 Climate data of February March and April 1993 in Carimagua

Month	Temperature (°C)			Precipitation (mm)
	Average	Minimum	Maximum	
February	28 1	22 1	33 6	49 6
March	26 2	22 2	31 6	251 0
April	26 3	23 0	31 1	233 2

Source Meteorological Department of Carimagua Research Station

The botanical composition of the native savanna in Carimagua consists for 39 3% of grasses 13 6% legumes and 9 0% Cyperaceae Other species occurring in this savanna are in decreasing order from 5 5% to 2 2% Labiatae Rubiaceae Melastomataceae Euphorbiaceae and Compositae Next to these there are other families in very low frequencies

The trial constitutes of two plots one with a medium stocking rate of 0 25 animal/ha and one with a high stocking rate of 0 5 animal/ha This is explained in Table 19 For this trial 8 zebu cows are used (4 in each stocking rate)

Table 19 Design of the trial

LSR (A)	HSR (A)	LSR (B)	HRS (B)
sub plot 2		sub plot 3	burnt 01 02 93
sub plot 12		sub plot 1	
sub plot 10		sub plot 11	
sub plot 8		sub plot 9	
sub plot 6		sub plot 7	
sub plot 4	burnt 01 03 93	sub plot 5	burnt 01 04 93

8 hectares
Low stocking rate (LSR)

4 hectares
High stocking rate (HSR)

LSR	=	4 animals grazing on 2	4 hectares =	0 25 animal/ha
HSR	=	4 animals grazing on 2	8 hectares =	0 50 animal/ha

Changes in botanical composition and the biomass production after different treatments of burning and under different grazing intensities were investigated Indicators for quality of regrowth and species are the preference of grazing animals for certain species or for certain ages of regrowth Weight development was delimitated by monthly weighing of the grazing animals coming directly from the field

The investigation were carried out during three consecutive months in the transition period from the dry to the wet season This means that first measurements were made in February which was the end of the dry season because the rainy season started very early this year The second measurements were of March and the last ones of April both in the initial period of the wet season

The treatments of burning and grazing were carried out at the same time in the 2 plots (HSR and LSR) The plots were divided into two times 6 subplots (A and B) The treatment consisted of burning one sub plot every first day of the month After a regrowth period of 15 days grazing started under both high stocking rate (HSR) and low stocking rate (LSR) in the part of the plot where the subplot with regrowth was situated After four weeks of grazing the animals were moved to the other 6 sub plots with a new regrowth subplot This is shown in Table 19 The variables to measure after the treatments are

<u>The composition and dynamics of the vegetation</u> In each sub plot permanent transects of 20 meters were made on which the occurring species at every 20 cm were recorded This was done after two weeks of regrowth (without grazing) and after six weeks of regrowth (four weeks grazing) Transects were also performed at every 10 cm on the diagonals of five protected squares of 1 x 1 meter in every subplot

<u>Standing dry phytomass of the pasture before burning</u> This was measured by cutting the vegetation of five squares of 1 x 1 meter before the burning at a 5 cm height The cut phytomass was dried and weighted

<u>Production of regrowth after burning with and without grazing</u> This was measured by regular cuttings of regrowth standing biomass at 5 cm height of five squares of 1 x 1 meter after two weeks regrowth (without grazing) and after six weeks regrowth (with four weeks grazing) Also standing phytomass after six weeks of protected regrowth These protected plots were situated within the sub plots so in the past these were either grazed under high stocking rate or low stocking rate

<u>The preference of grazing animals for sub plots differing in regrowth stage and grazing intensity</u> This was measured by observation of preference of grazing animals for sub plots in a certain regrowth stage The animals were observed from a hiding place without disturbing the behavior of the animals These observations took place every 14 days for 2 x 12 hours First of these observations were made in March when the animals started grazing the plot

3 RESULTS

The influence of the treatments on the vegetation are shown in the next graphs and tables Since it was not possible to analyze the data in a statistical way it is assumed that a difference of 2% has some significance Similarly changes in frequency percentage greater than 5% are taken as indicative of important changes in the botanical composition

3 1 Vegetation Dynamics

To give more conveniently arranged data these were reduced towards species with a frequency percentage higher than 10% at any regrowth stage The species apart from these are called others

3 1 1 Influence of burning

The effect of the time of burning on the botanical composition was shown by comparing the regrowth vegetation of plots differing in date of burning with their former vegetation This was calculated in Table 20

These data are presented more clearly to facilitate comparison of the effect of different dates of burning in Table 21 and Figures 18 to 22

Table 20 The influence of burning on the frequency (%) of species after six weeks of protected regrowth

Species		BURNING					
		February		March		April	
		Stocking rate					
Nr	Name	High	Low	High	Low	High	Low
1	*Andropogon bicornis*	1 4	1 0	14 0	0 0	0 7	1 8
21	*Hyptis* spp	1 6	0 7	1 5	4 2	15 4	10 5
24	*Andropogon*	11 8	5 0	7 0	14 7	1 7	2 6
29	*leucostachyus*	11 0	10 9	12 8	3 3	7 6	0 1
30	*Otachyrium versicolor*	0 5	12 7	8 5	22 1	9 3	22 9
	Paspalum pectinatum						
33	*Axonopus purpusii*	9 5	10 1	31 6	0 4	6 5	0 0
37	*Andropogon selloanus*	4 4	20 3	8 7	8 5	5 8	1 7
43	*Trachypogon vestitus*	45 8	22 3	17 6	27 3	9 1	48 5
oo	Other species	0 4	8 6	4 1	6 4	3 3	20 3
46	Bare soil	28 0	25 8	0 0	4 1	0 0	0 0

3 1 2 Influence of grazing

See Table 22 and Figures 23 and 24

3 2 Phytomass

3 2 1 Above phytomass

Data of the standing living biomass before burning and biomass production by regrowth after burning are summarized in Table 23 The plots are different in date of burning and grazing intensities

Table 21 The occurrence of species in the six weeks old regrowth vegetation after burning without grazing

	F				M				A			
NR	+ +	+			+ +	+			+ +	+		
1								X				
21									X			
24		X		X	X							
29	X					X						X
30		X				X		X	X			
33			X			X						X
37				X			X					X
43			X				X				X	
oo		X						X		X		
46	X							X		X		

+ + = increase in frequency percentage in both plots
\+ = increase in frequency percentage in one plot
= *decrease in frequency percentage in both plots*
= decrease in frequency percentage in one plot
X = change in frequency percentage higher than 5%
(for names of species see Table 20)

The effect of the time of burning on the standing biomass has been analyzed by comparing average above ground dry matter in protected areas six weeks after burning (cages) at different dates February was a very dry month with precipitation during the six weeks after burning of 36 mm Average above ground biomass of undisturbed regrowth after burning was 34 3 g/m² The results of the measurements in the rainy season with a precipitation during the six weeks regrowth of 304 mm in March and 476 mm in April showed an average above ground standing biomass of 94 9 g/m² and 118 5 g/m² respectively The biomass production after six weeks of undisturbed regrowth in the rainy season were three to four times as high as the results of the measurements taken at the end of the dry season

3 2 2 Below phytomass

These data show a very high biomass for a rest of two weeks compared with the other rests to graze after burning Also significant difference can be observed between stocking rate with medium stocking rate we can observe very high root biomass four time those of low stocking rate (Table 24)

The reasons of these differences have to be investigate (botanic composition compactation fire etc)

Table 22 Changes in frequency of species after grazing burnt sub plots

SPECIE		HIGH STOCKING RATE			
Nr	Name	February	March	April	Average
1	*Andropogon bicornis*	0 0	1 7	0 1	0 5
21	*Hyptis* spp	0 9	10 0	9 4	6 8
24	*Andropogon leucostachys*	11 6	12 4	3 7	9 2
29	*Otachyrium versicolor*	1 9	9 4	1 0	2 8
30	*Paspalum pectinatum*	3 0	0 5	10 7	4 7
33	*Axonopus purpusii*	0 5	12 8	3 9	3 1
37	*Andropogon selloanus*	4 1	11 3	1 4	2 9
43	*Trachypogon vestitus*	6 7	5 8	9 4	3 4
oo	Other species	15 3	12 2	12 3	13 3
46	Bare soil	15 3	16 7	0 7	10 9

SPECIE		LOW STOCKING RATE			
Nr	Name	February	March	April	Average
1	*Andropogon bicornis*	0 0	0 0	0 0	0 2
21	*Hyptis* spp	3 0	1 5	2 4	0 7
24	*Andropogon leucostachys*	1 0	15 1	4 0	0 6
29	*Otachyrium versicolor*	0 6	7 8	2 0	2 1
30	*Paspalum pectinatum*	11 9	25 8	20 6	19 4
33	*Axonopus purpusii*	2 4	0 8	0 0	1 1
37	*Andropogon selloanus*	2 0	4 4	1 5	2 6
43	*Trachypogon vestitus*	1 8	6 5	21 8	5 7
oo	Other species	13 9	5 6	1 2	6 9
46	Bare soil	13 9	28 7	4 5	15 7

3 2 3 **Site preference of grazing** (Table 24)

The data of the field observation of animals grazing the regrowth are shown in Table 25 and Table 26

For the analysis of the species preference for grazing animals preference indices (PI) were calculated and reported in Tables 27 and 28

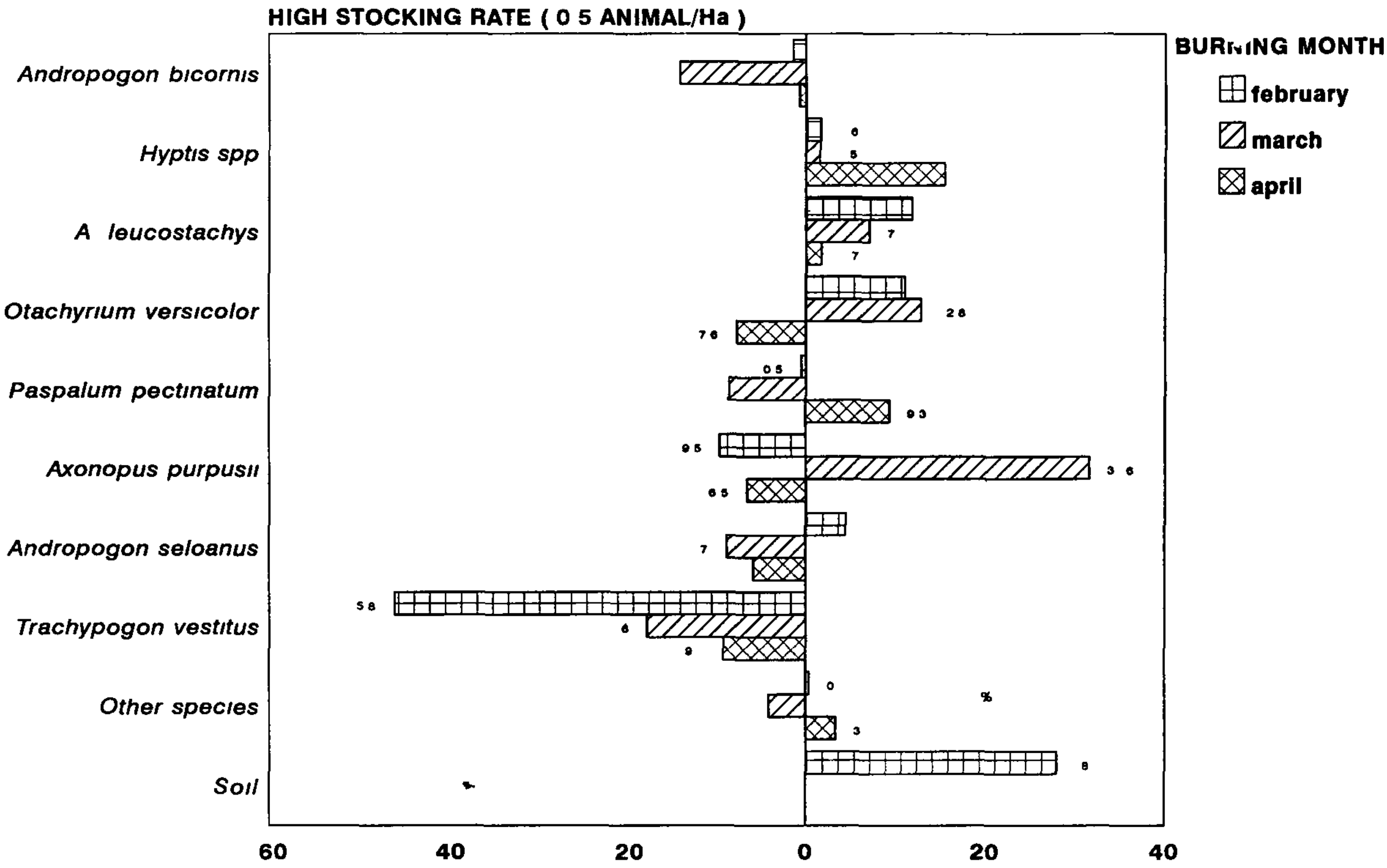


FIGURE 18 EFFECT OF BURNING ON VEGETATION DYNAMICS
RELATIVES CHANGES 6 WEEKS AFTER BURNING (IN DRY AND BEGINNING OF WET SEASON)

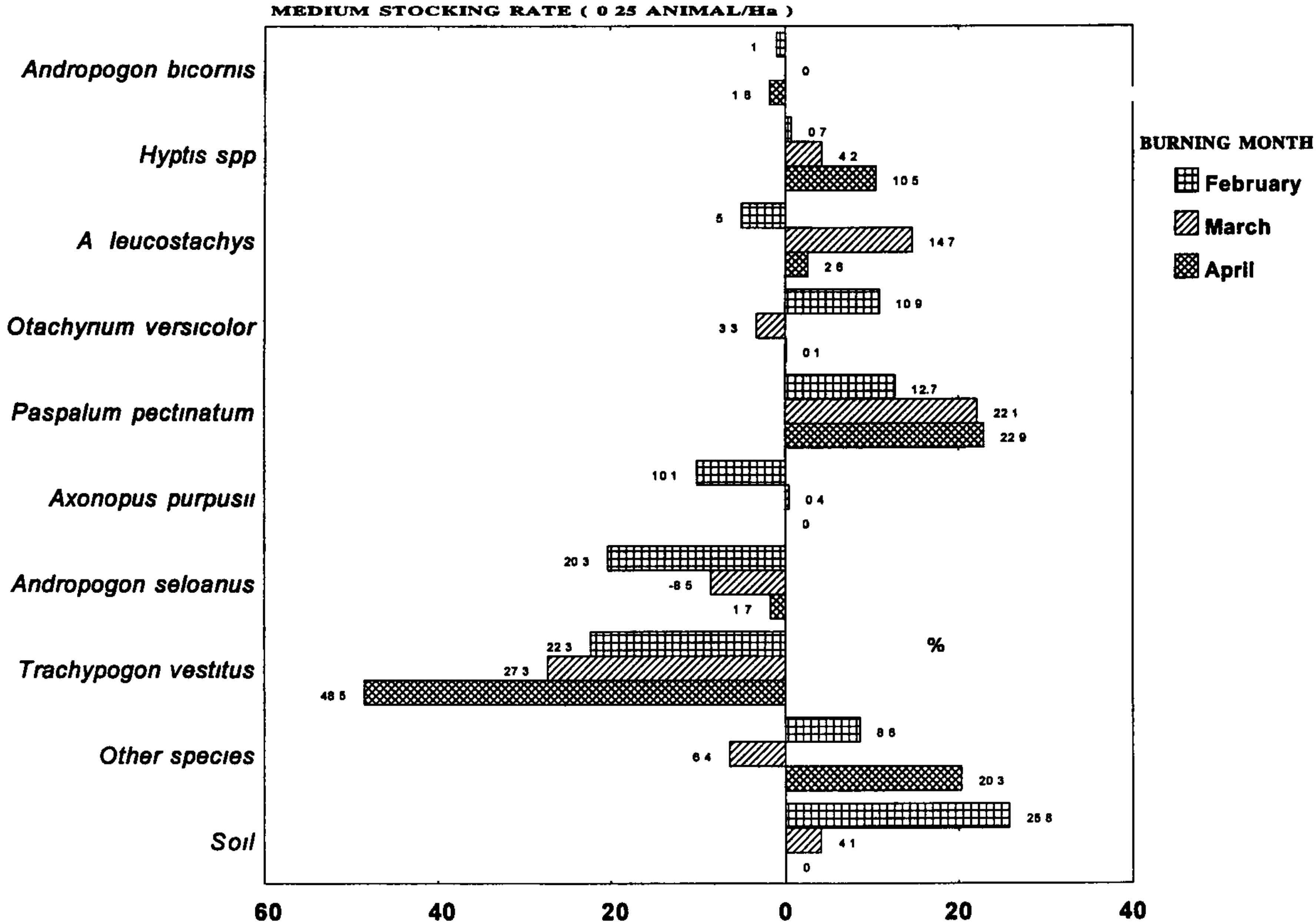


Figure 19 Effect of burning vegetation dynamics
Relative changes 6 weeks after burning in the dry beginning of wet season

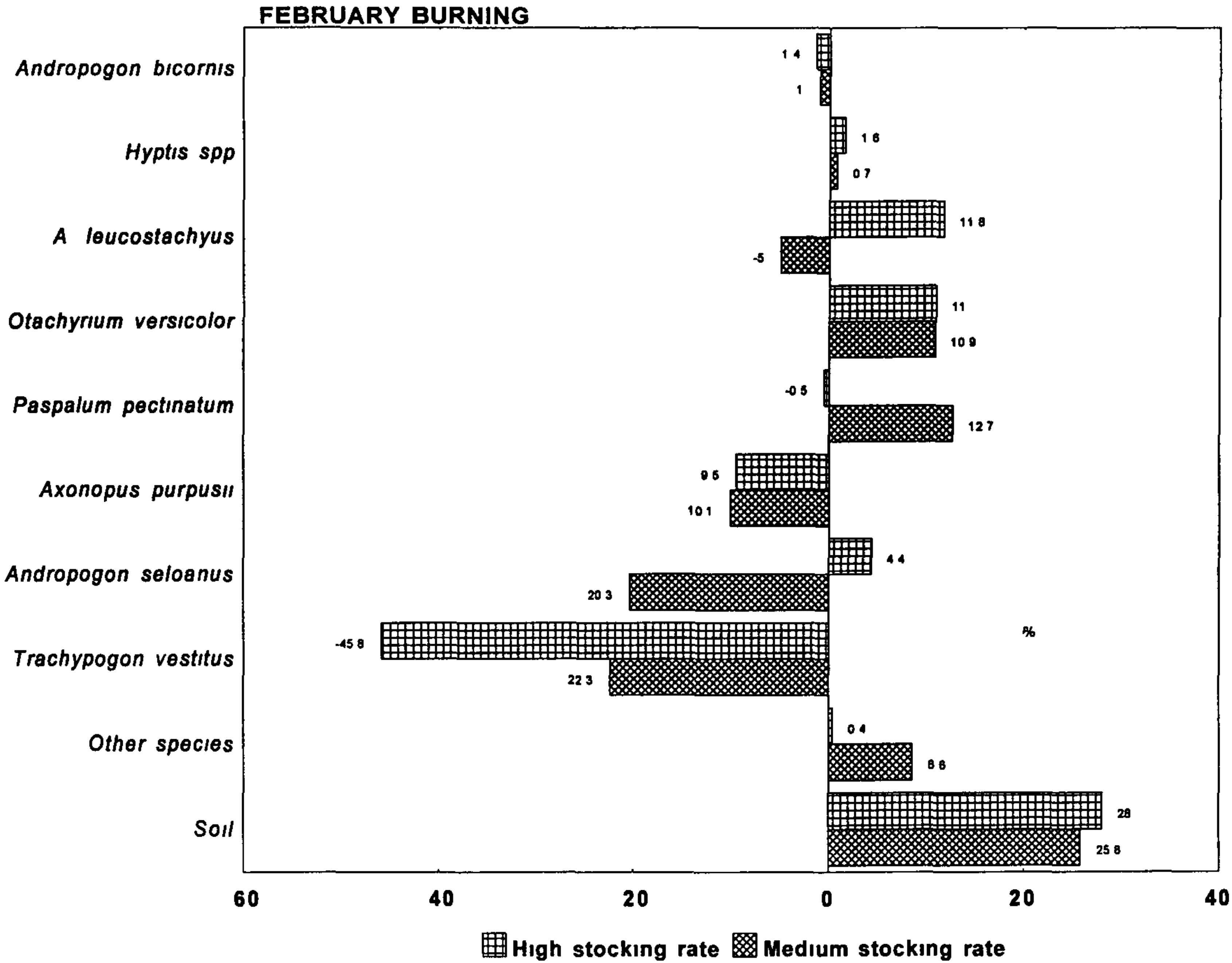


Figure 20 Effect of burning on vegetation dynamics
Relatives changes 6 weeks after burning in dry and beginning of wet season

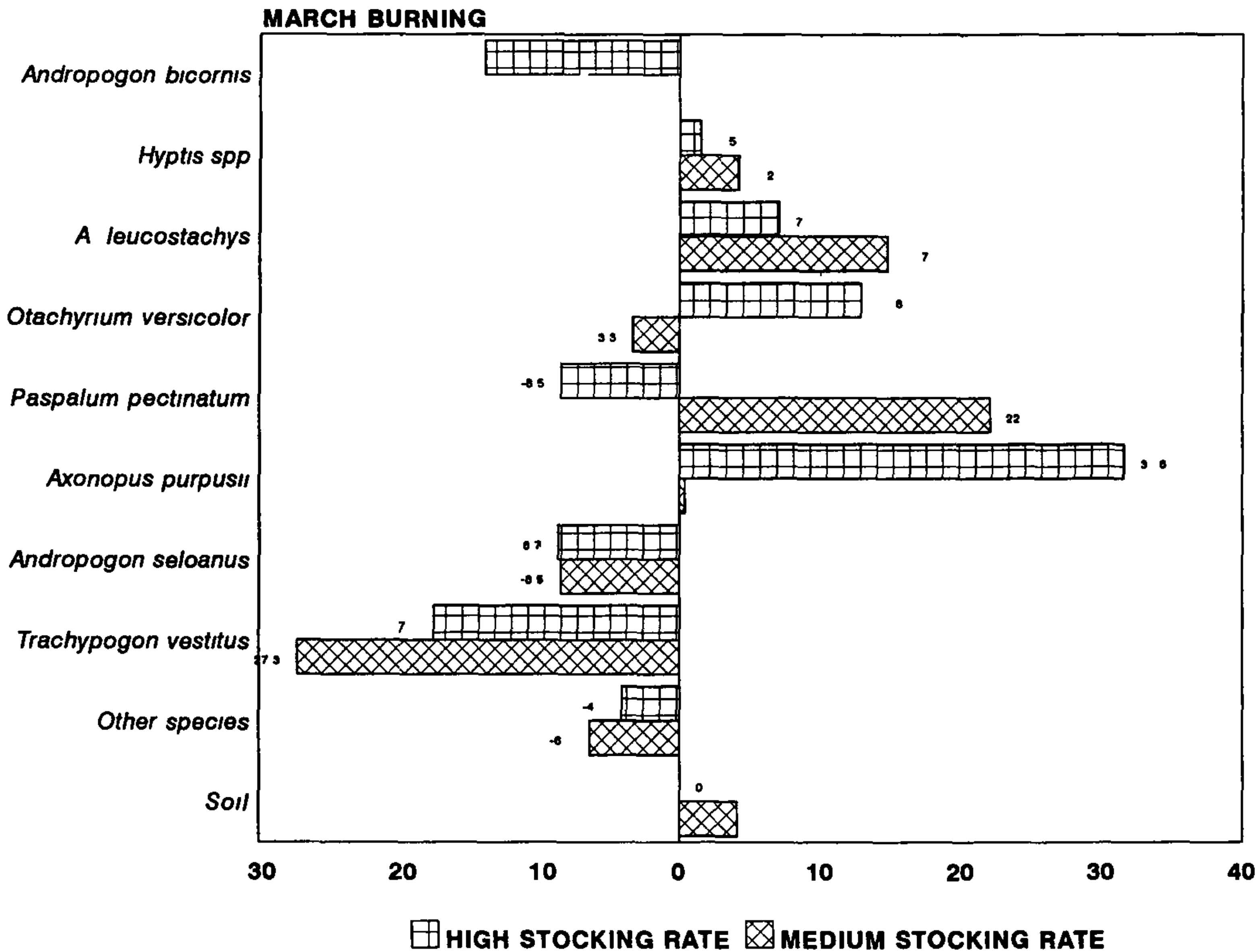


FIGURE 21 EFFECT OF BURNING ON VEGETATION DYNAMICS
RELATIVES CHANGES 6 WEEKS AFTER BURNING IN DRY AND BEGINNING OF WET SEASON

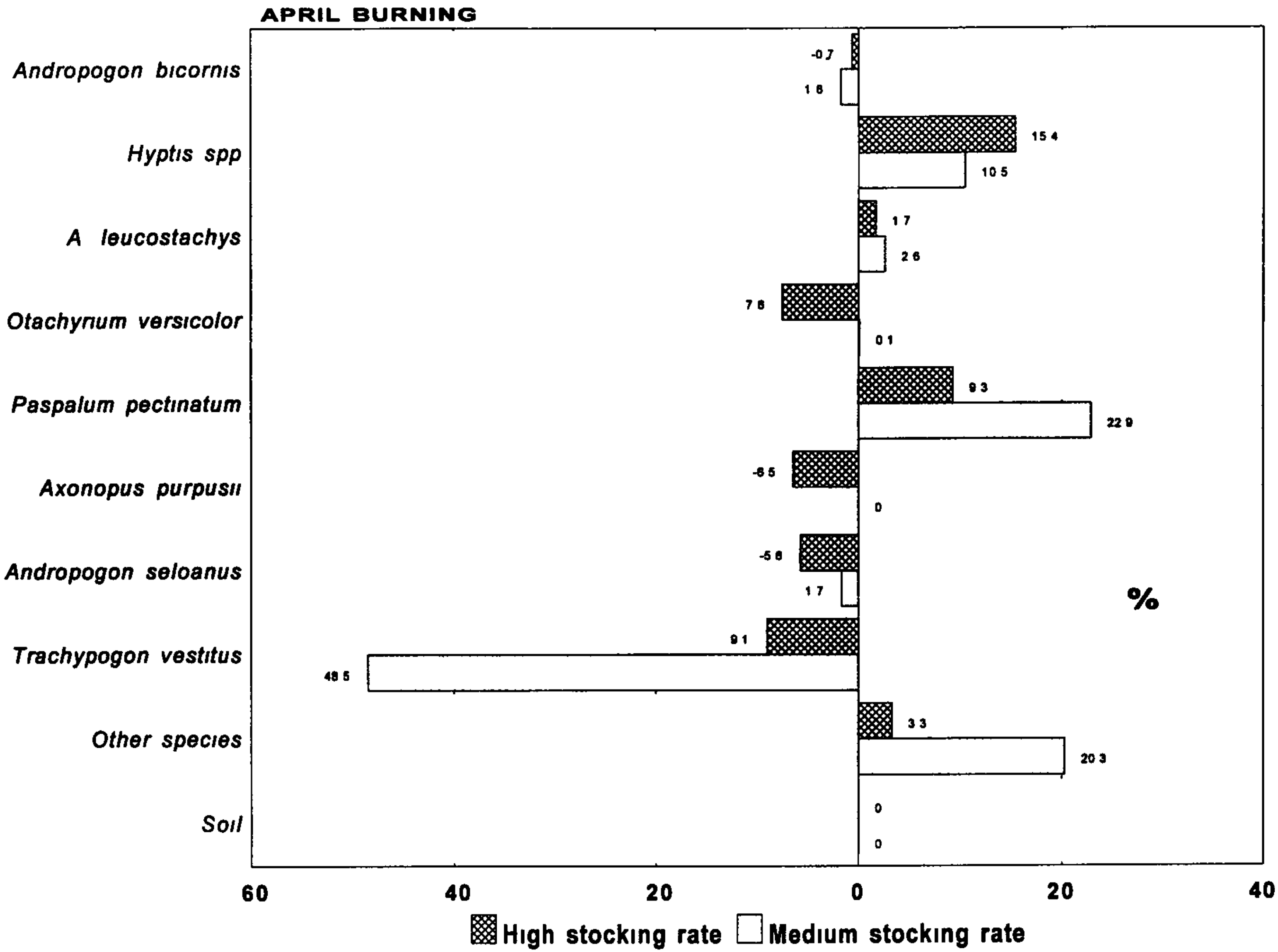


Figure 22 Effect of burning on vegetation dynamics

Relatives changes 6 weeks after burning in dry and beginning of wet season

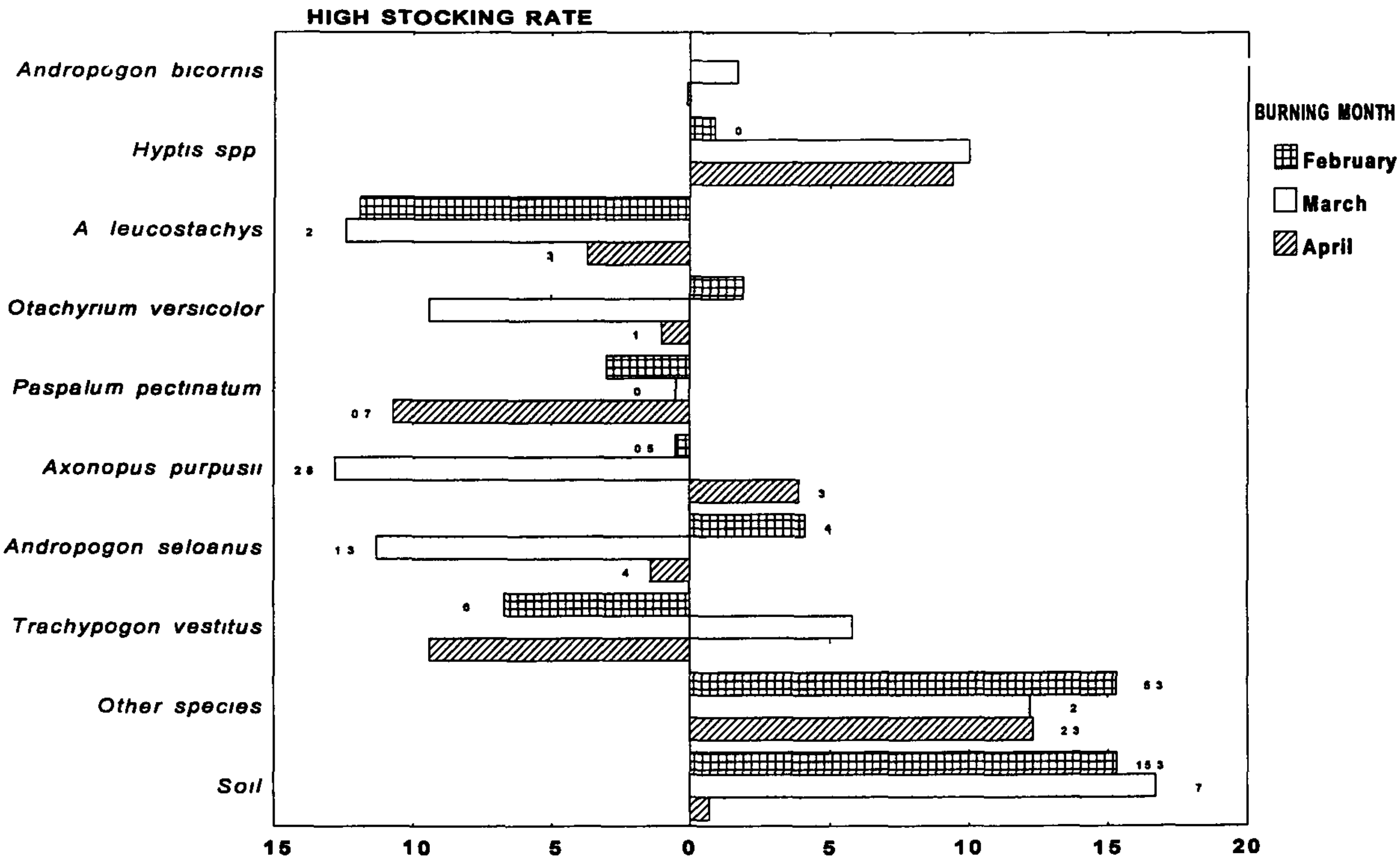


Figure 23 Vegetation dynamics under grazing

Effects of high stocking rate on the frequency (%) of species in a 6 weeks old regrowths of burnt savanna

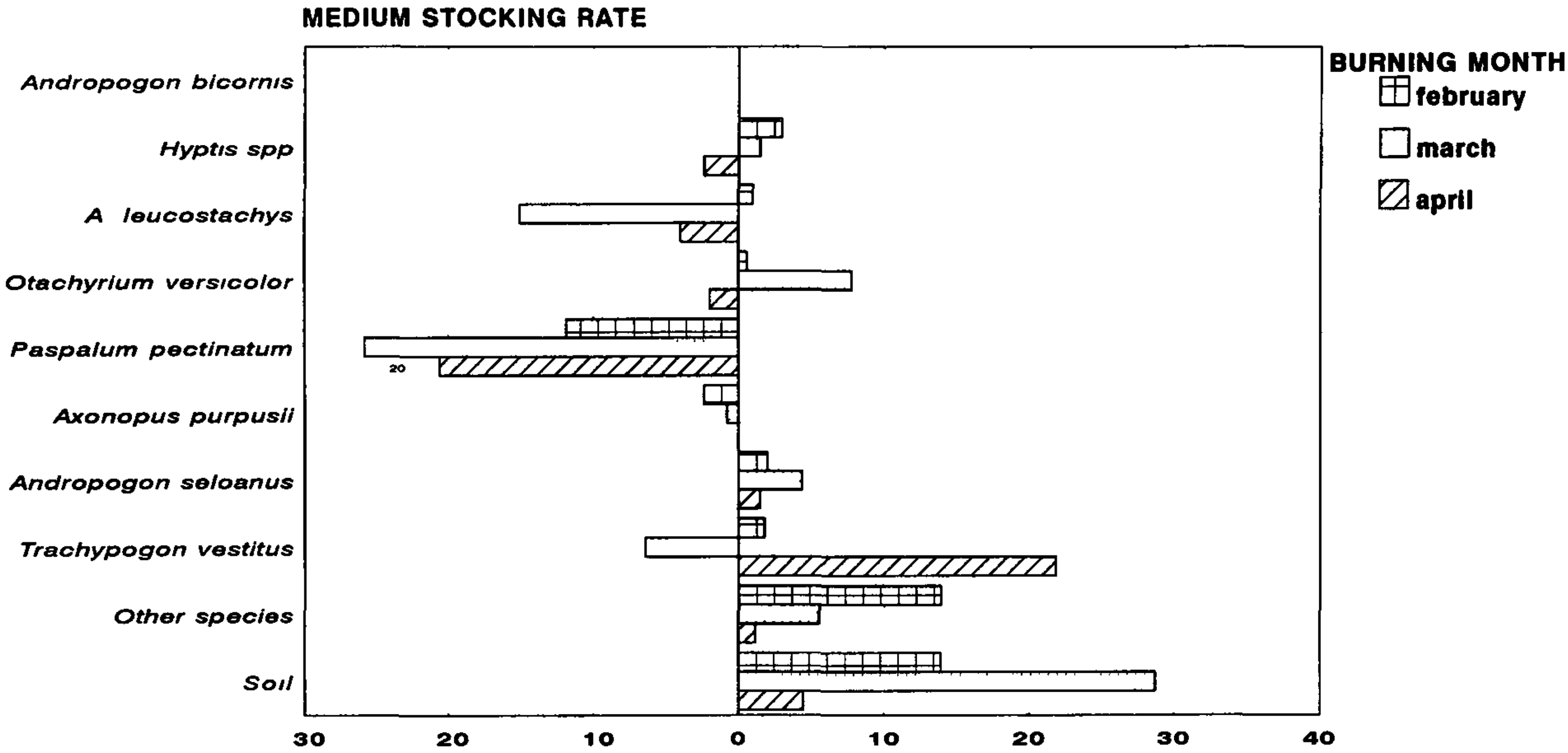


FIGURE 24 VEGETATION DYNAMICS UNDER GRAZING
EFFECT OF MEDIUM STOCKING RATE ON THE FRECUENCY (%) OF SPECIES IN A 6 WEEKS OLD REGROWTHS OF BURNT SAVANNA

Table 23 Standing phytomass before burning and regrowth after burning with without grazing

	Date of burning	February	March	April
		g DM/m²		
High Stocking Rate	Before burning	393 9	257 7	362 6
	0 week regrowth	0 0	0 0	0 0
	2 weeks regrowth	7 5	8 8	10 6
	6 weeks regrowth*	6 4	4 7	34 1
	6 weeks regrowth in cage	35 3	88 6	136 2
Low Stocking Rate	Before burning	338 8	183 9	295 7
	0 week regrowth	0 0	0 0	0 0
	2 weeks regrowth	10 9	5 4	29 9
	6 weeks regrowth	2 8	21 2	56 0
	6 weeks regrowth in cage	25 9	115 3	104 7
NB 6 weeks regrowth + 4 weeks consumption				

Table 24 Influence of rest before grazing (0 2 4 8 weeks) and stocking rate after burning on below phytomass (roots biomass)

	ROOTS BIOMASS (0 80 cm)			
	g DM/15 9 cm²	g DM/m²	kg DM/ha	Duncan grouping
Rest (weeks)				
0	0 86	540	5400	B
2	2 01	1264	12264	A
4	0 92	579	5790	B
8	0 98	616	6160	B
Stocking rate (ha/animal)				
Low 6	0 67	421	4210	C
Medium 4	1 71	1075	10750	A
High 2	1 31	824	8240	B

Means with the same letter are not significant different

Table 25 Site preference of animals grazing 2 4 weeks old regrowth Time spent between 6 00 a m and 6 00 p m in each sub plot (percentage of time)

Sub plots age of regrowth (days)	March (2 weeks regrowth)		March (4 weeks regrowth)		April (2 weeks regrowth)	
	Stocking rate					
	High	Medium	High	Medium	High	Medium
14	48 0	49 0			30 4	27 6
28			56 3	53 7		
72	29 5	17 7			59 2	52 1
86			31 2	32 7		
135	20 9	30 6			3 5	8 9
149			5 7	8 1		
196	0 8	1 3			3 2	6 1
210			7 2	3 7		
258	0 8	0 0			2 2	3 3
272			0 6	0 5		
315	0 0	1 5			1 7	2 2
329			1 4	0 2		

Table 26 Regrowth quality

Regrowth age (weeks)	Protein (% DM)	IVDMD (% DM)
2	7 7	44 6
4	6 2	38 0
8	4 6	31 2

Table 27 Species preference (preference index) Species selected by cattle on four weeks regrowth after burning most occurring species (fp>10%)

	BURNING					
	FEBRUARY		MARCH		APRIL	
	fp (%)	PI (%)	fp (%)	PI (%)	fp (%)	PI (%)
HIGH STOCKING RATE						
Andropogon bicornis	0		1 7	52 9	1 5	100 0
Hyptis spp	2 9	0	2 1	61 9	31 0	0
Andropogon leucostachys	2 4	79 2	14 3	0	1 1	72 7
Otachyrium versicolor	12 9	36 4	7 4	5 4	2 2	0
Paspalum pectinatum	0		0 4	100 0	4 5	0
Axonopus purpusii	0 5	100 0	25 7	44 4	4 9	28 2
Andropogon selloanus	12 1	8 3	4 1	70 7	11 8	72 0
Trachypogon vestituts	13 3	60 9	9 2	18 5	9 0	42 2
MEDIUM STOCKING RATE						
Andropogon bicornis	0 5	100 0	0		0	
Hyptis spp	0		2 7	100 0	8 5	0
Andropogon leucostachys	1 0	100 0	5 7	0	3 0	0
Otachyrium versicolor	11 5	34 8	10 3	35 0	1 1	0
Paspalum pectinatum	1 5	66 7	2 2	77 3	25 1	17 5
Axonopus purpusii	0 5	0	0		0	
Andropogon selloanus	2 0	100 0	4 4	72 7	1 5	0
Trachypogon vestituts	33 5	43 3	24 0	49 6	28 0	0

fp frequency of presence (%) for each specie
PI preference index (%) = number of plants grazed x 100 / number of total plant for (each serie) or frequency of consumption x 100 / frequency of presence

In February at low stocking rate selectivity of *Andropogon bicornis* (1) *Andropogon leucostachys* (24) and *Andropogon selloanus* (37) was very high and selected to a lesser extend were *Paspalum pectinatum* (30) *Panicum versicolor* (29) and *Trachypogon vestitus* (43) Not selected was *Axonopus purpusii* (33) At high stocking rate there was less selectivity among species Selected in order of PI (%) were *Axonopus purpusii* (33) *Andropogon leucostachyus* (24) *Trachypogon vestitus* (43) and *Panicum versicolor* (29) PI of *Andropogon selloanus* (37) was very low Not selected were *Hyptis* sp (21) and *Paspalum pectinatum* (30)

In March the differences in selection of species between high stocking rate and low stocking rate were small Species selected at high stocking rate were *Andropogon bicornis* (1) *Hyptis* sp (21) *Paspalum pectinatum* (30) *Andropogon selloanus* (37) *Axonopus purpusii* (33) *Panicum versicolor* (29) and *Trachypogon vestitus* (43) Here *Andropogon leucostachyus* (24) was not selected despite its higher frequency percentage compared to the plot at low stocking rate

Table 28 Selectivity of minor species (FP>10%) by grazing animals

Species (No) (No see Annex 1)		February		March		April	
		fp(%)	PI(%)	fp(%)	PI(%)	fp(%)	PI(%)
High stocking rate							
ANCEPS	2	0		0		0	
AXAUR	3	0		0		0	
CAMPO	4	0		0		0	
DICRO	13	6 7	14 9	8 5	6 0	2 9	0
ERIO	14	0		0		0 8	0
ELIO	15	0		0		0	
ESKIZA	16	0		0		0 1	0
GALA	18	0		0 9	0	0	
GIMNO	19	0		0		8 7	
LEPTO	23	0 5	80 0	0 4	0	3 3	0
RUYEI	34	0		0		0	
RHYNBAR	35	0		0		6 3	0
SETA	38	0 5	0	3 4	0	6 8	16 2
SIPANE	39	1 9	0	2 1	0	4 5	0
TRAPE	44	1 0	100 0	0		0 4	100 0
Low stocking rate							
ANCEPS	2	0		1 3	30 8	0	
AXAUR	3	0		0		0	
CAMPO	4	0		0		0 4	0
DICRO	13	1 0	50 0	6 4	6 3	1 5	0
ERIO	14	0		0		2 2	0
ELIO	15	0		0		2 2	18 2
ESKIZA	16	0		0		0	
GALA	18	0		2 2		0	
GIMNO	19	0		0		5 6	0
LEPTO	23	0		0		0	
RUYEI	34	0		0		0	
RHYNBAR	35	0		0		1 9	0
SETA	38	0		0		0	
SIPANE	39	2 5	0	5 0	0	4 5	0
TRAPE	44	2 0	75 0	0		2 6	15 4

Species selected at low stocking rate are in order of PI(%) *Hyptis* sp (21) *Paspalum pectinatum* (30) *Andropogon selloanus* (37) *Panicum versicolor* (29) and *Trachypogon vestitus* (43) Also here *Andropogon leucostachyus* (24) was not selected despite its presence *Andropogon bicornis* (1) and *Axonopus purpusii* (33) are not mentioned here because these were not present in the regrowth as in the sub plot burnt in April The first one of these mentioned was not present in the vegetation before burning the other one was with a frequency percentage of just 0 4% and a frequency percentage in regrowth of the cage of 0 8%

In April diversity in selection of species was highest especially at high stocking rate in April *Andropogon bicornis* (1) *Andropogon selloanus* (37) *Trachypogon vestitus* (43) and *Axonopus purpusii* (33) were selected more at high stocking rate compared with low stocking rate On the other hand *Andropogon bicornis* (1) and *Axonopus purpusii* (33) were not present at all in the vegetation of the plot at low stocking rate and therefore could not be selected at all *Andropogon selloanus* (37) and *Trachypogon vestitus* (43) were not selected in April at low stocking rate despite their presence in contrast to the high stocking rate where they were present and selected

In the group of species with frequency percentage less than 10% the diversity in selection was highest in the plot at low stocking rate In February differences in botanical composition between the plots at high stocking rate and low stocking rate did not occur But selectivity for species was very clear *Trasya petrosa* (44) was highly selected 100% and 75% for the plot at high stocking rate and low stocking rate respectively

Selection of *Leptocoryphium lanatum* (23) was 80% at high stocking rate and 25% at low stocking rate and *Dichromena ciliata* (13) was selected with a PI of 14 9% at high stocking rate and 50% at low stocking rate The high selection in March of *Axonopus anceps* (2) at low stocking rate (PI = 30 8%) contributed to the difference (Table 28) But at high stocking rate in March this species could not be selected because it was not present in the natural vegetation nor in the regrowth Besides this the Figures of plots at high stocking rate and low stocking rate are almost equal also in this period selectivity of species less frequently occurring in the native savanna was very low Differences in selection of *Elyonorus candidus* (14) and *Trasya petrosa* (44) in April were the main contributors to the difference occurring between high stocking rate and low stocking rate The presence of *Elyonorus candidus* (14) in the native vegetation before burning was 0 4% at high stocking rate and 2 4% at low stocking rate Frequency percentage of this species was zero in the regrowth vegetation in the plot at high stocking rate At low stocking rate the regrowth of these species (fp = 2 2%) was consumed with a PI of 18 2% Selectivity of the other species was very low in this period at both high stocking rate and low stocking rate

4 DISCUSSION AND CONCLUSIONS

4 1 Vegetation dynamics

4 1 1 Burning

Specie specific competitive ability and time of burning (water availability) are very important for regrowth after burning The botanical composition after burning changed towards either species resistant to burning adapted to water stress or species able to benefit from the improved growth conditions by the disappearance of species

For some annuals growth was initiated by the temperature effect of fire and for some species growth conditions improved because of reduced competition for growth factors with other plants

Regrowth of annuals was poor after burning in the dry period though *Hyptis* sp took advantage of the decrease in competition with other plants for growth factors like water light and nutrients Under circumstances with higher water availability recovery of *Hyptis* sp increased even more Species with a germination which was initiated by the first rains of the wet season were killed by the burning The decrease in number of annual species after burning can not be generalized because some annuals start their growth cycle another time because of their strategies adapted to the specific environmental factors

Good recovery under wet circumstances was also shown by the species *Andropogon leucostachyus* and *Paspalum pectinatum* The key species for management of this type of savanna *T vestitus* decreased in frequency percentage in the six weeks old regrowth after all burning treatments This was partly replaced by *Paspalum pectinatum* which is another important species in the savanna of Carimagua This decrease in the key species might stay so or may recover in time but data about further developments are lacking in this experiment

Under wet circumstances when soil was suturated with water and precipitation was high vegetational recovery after burning was fast and considerable

4 1 2 Grazing

Introducing grazing two weeks after burning caused increases in the number of species under all grazing treatments mainly contributed by annual species An increase under grazing also occurred for *Hyptis* sp This was probably related to the reduced competition for growth factors with other species and improved growth conditions because of the interruption of the plant by grazing This effect of grazing on the vegetation and seemed to be related to stocking rate

4 2 Site preference of grazing animals

By comparing data in Table 8 the site preference for different stocking rates were obtained The biggest differences occurred in the first observations in March The animals in the plot at HSR spent 11 8% more of their grazing time in the sub plot with regrowth of 72 days old than the animals in the plot at LSR These latter animals instead spent more time grazing in the sub plot with 135 days old regrowth (difference of 10 5%) The same occurs in the measurements of April although to a lower extent animals in the plot at HSR spent 7 1% more grazing time in the sub plot with 72 days old regrowth than animals in the plot at LSR These spent this time in the following sub plot with a regrowth of 135 days old

Striking is the difference occurring in time spent grazing in the sub plots between March and April In March the animals preferred to graze the sub plot with youngest regrowth of 14 days old as expected This is contrast to the data of April when the animals preferred to graze the sub plot with 72 days old regrowth to the plot most recently burnt for grazing Differences in average temperature and precipitation of these months were small But here one should realize that in March part of the precipitation was used to moisten the dry ground which reduced available water for plant growth This resulted in an above ground dry matter availability of 8 8 g/m^2 at HSR and 6 5 g/m^2 at LSR in March In April these figures were 10 6 g/m^2 at HSR and 29 9 g/m^2 at LSR

4 3 Species preference

Species preferred by grazing animals at young age were *Andropogon bicornis Axonopus purpusii Andropogon selloanus* and *Trachypogon vestitus* Species decreasing under the grazing treatments were *Andropogon leucostachyus* and *Paspalum pectinatum Trachypogon vestitus* the key species in this savanna type showed decreases in frequency percentage under grazing at high stocking rate and increases in frequency percentage under grazing at medium stocking rate after burning in February as well as in April But the opposite effect occurred under grazing after burning in March This could not be explained with data from this trial but might be caused by environmental factors not investigated here Therefore it is not possible to make here any conclusions about the influence of grazing on the occurrence of *Trachypogon vestitus*

Under grazing the occurrence of bare soil was increased (Table 20) which seemed to be related to water availability (precipitation) and to stocking rate After burning in the dry season the increase in occurrence of bare soil was equal for both stocking rate in the regrowth of March the increase in the occurrence of bare soil due to grazing was highest at low stocking rate while in the regrowth of April the occurrence of bare soil due to grazing was very small

4 4 Phytomass and production

Grazing activities also caused decreased in the above ground biomass which also seemed to be related to water availability (precipitation) and to stocking rate

Absolute reductions in above ground regrowth biomass due to grazing were equal for both stocking rate in February were highest at medium stocking rate in March and were highest at high stocking rate in April although in all of the months relative reductions were highest at high stocking rate

4 5 Animal performance

These features are reflected in the lifeweight changes of animals grazing under this management system Animals grazing six weeks old regrowth after burning in February severely loose weight due to insufficiently available good forage The same treatments in March lead to a higher availability of green forage though and unexpected loss in liveweight of animals grazing this vegetation occurs This might be explained by the change in gutfill which causes temporary reductions in liveweight when diets consist of high protein concentrations after a period of low protein containing diets After the treatment in April animals show compensatory intake and compensatory liveweight gains

This leads to the conclusion that although this experiment last for only three of in total 12 months of one year the aim of the proposed management system is not reached fluctuations in weight gain of grazing animals do still occur Although green material is available in the dry month the insufficiency limits production Therefore it is proposed to increase the areas for burning in the dry season to increase the quantity of green forage on offer during this period Because the experiment lasted only for three months this proposal needs more investigation for the effect of annual burning on the botanical composition by monthly measurements of all plots

ANNEX 1

LIST OF ABBREVIATIONS OF SPECIES

Nr	Abbreviation	Family	Specie
1	ABICOR	Poaceae (a)	*Andropogon bicornis*
2	ANCEPS	Poaceae (p)	*Axonopus anceps*
3	AXAUR	Poaceae	*Axonopus aureus*
4	CAMPO	Poaceae	*Paspalum campestre*
5	CAPICA	Fabaceae	*Stylosanthes capitata*
6	CASEA	Flacourtiaceae	*Casearia ulmifolia*
7	CASSIA	?	*Cassia* sp
8	CENTRO	Fabaceae	*Centrosema* sp
9	CLITO	Fabaceae	*Clitoria guianensis*
10	CYPURA	Iridaceae	*Cypura paludosa*
11	DESMO	Fabaceae	*Desmodium barbatu*
12	DICO	?	*Dicotiledoneas* spp
13	DICRO	Cyperaceae	*Dichromena ciliata*
14	ELIO	Poaceae	*Elyonurus candidus*
15	ERIO	Fabaceae	*Eriosema* spp
16	ESKIZA	Poaceae	*Schizachyrium hirtiflorum*
17	FILAN	Euphorbiaceae	*Phyllanthus niruri*
18	GALA	Fabaceae	*Galactia glauscesens*
19	GIMNO	Poaceae (a)	*Gymnopogon foliousus*
20	GRAM	Poaceae	*Gramineas* spp
21	HYPTIS	Labiatea (a)	*Hyptis* spp
22	IPOMO	Convulvulaceae	*Ipomoea*
23	LEPTO	Poaceae (p)	*Leptocoryphium lantum*
24	LEUCO	Poaceae (p)	*Andropogon leucostachyus*
25	LINDA	Scrophulariaceae	*Lindernia diffusa*
26	MELO	Sterculiaceae	*Melochia villosa*
27	MIMO	Mimosaceae	*Mimosa* spp
28	OVAL	Fabaceae	*Desmodium ovalifolium*
29	PAVER	Poaceae (p)	*Panicum versicolor*
30	PEPE	Poaceae (p)	*Paspalum pectinatum*
31	PERATA	Poaceae	*Imperata brasiliensis*
32	PODO	Cyperaceae	*Rhynchospora podeosperma*
33	PURPU	Poaceae (p)	*Axonopus purpusii*
34	RUYEI	Poaceae	*Panicum rudgei*
35	RYNBAR	Cyperaceae	*Rhynchospora barbata*
36	RYNCON	Cyperaceae	*Rhynchospora confinis*
37	SELOA	Poaceae (p)	*Andropogon selloanus*
38	SETA	Poaceae (p)	*Setaria geniculata*
39	SIPANE	Rubiaceae	*Sipanea pratensis*
40	STELLA	Poaceae (p)	*Paspalum stellatum*

41	STYLO	Fabaceae	*Stylosanthes* sp
42	TINCTA	Poaceae (p)	*Aristida tincta*
43	TRACHY	Poaceae (p)	*Trachypogon vestitus*
44	TRAPE	Poaceae (p)	*Thrasya petrosa*
45	TRAPLU	Poaceae (p)	*Trachypogon plumosis*

a = annual
p = perennial

CHAPTER III

PROJECT TC 01 PROTOTYPE SUSTAINABLE CROPPING SYSTEMS FOR THE BRAZILIAN CERRADOS

Miguel A Ayarza (TL)

INTRODUCTION

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

CIAT and EMBRAPA carried out pioneering studies to characterize the Cerrados according to major agroecological classes (Project TC03) After prioritizing these classes the Center CPAC/EMBRAPA and the Federal University of Uberlandia initiated on station and on farm studies to develop land management options for sustainable development

PURPOSE

Generate technologies and land management strategies for sustainable agricultural development in the Brazilian Cerrados

OUTPUTS

1 Prototype technologies that allow lasting improvement in the efficiency of resource use and that control soil and water degradation
2 Identification of soil indicators of sustainability

ACTIVITIES

A series of on station and on farm activities were carried out during the last two years to develop sustainable crop pasture systems with the participation of several national and international institutions Below are reported the activities methodologies and main results

1 Development of Improved Agropastoral Systems

The impact of the rice pasture technology to reclaim degraded pastures in the cerrados has been demonstrated by researchers from the National Center for Research in Rice and Beans (CNPAF) New rice varieties and other crop components are currently under testing to improve crop options However little has been done to increase pasture components especially forage legumes Legumes are important during the dry season when the quality of improved grasses drops and improve N availability and soil organic matter quality avoiding pasture degradation Less work has been done to select pasture components for rotations with crops in intensive management systems A collaborative effort was established between our Section the Tropical Forage Program of CIAT and the University of Uberlandia to increase pasture options Activities included a) small plot trials to select promising germplasm b) quantification of the tradeoffs between crop and pasture components and 3) multiplication of promising forage species for on farm testing

1 1 Selection of pasture germplasm for agropastoral systems *M Ayarza (TLP) and E A Pizarro (TFP)*

Testing activities started in 1992 planting several grass and legume accession with rice and corn in several farms in Uberlandia in large plots The results of the work showed that *Stylosanthes guianensis cv mineirao* a forage legume recently released by EMBRAPA was successfully established in rice pasture systems in clay and sandy soils In contrast establishment of the legume was poor when planted with corn and Panicum Vencedor under intensive use of inputs During the present year we tested other promising grass and legume options for rice and corn systems A mixture of *Paspalum atratum* BRA 9610 and *Stylosanthes mineirao* was planted simultaneously with rice to reclaim a degraded pasture of *B ruziziensis* in a sandy soil of Uberlandia Simultaneously we tested the adaptation and yield potential of promising grass legume mixtures to the conditions of the region Twenty one legumes and nineteen grasses were planted in small plots using a modified regional trial arrangement Grasses were planted with a common legume *(Stylosanthes guianensis cv mineirao*) and legumes with a common grass *(Brachiaria decumbens cv Basilisk*)

Establishment of the *Paspalum* and Stylosanthes mixture planted simultaneously with rice was excellent Pasture was ready for grazing after rice harvesting On the other hand rice yields were reduced by 30% due to competition from the remaining pasture of *B ruziziensis* Average yields were approximately t 1 8 ton/ha Animal performance measurements started in May 1994

The results of the first year of evaluation of the small plot experiment showed that Stylosanthes was established well with most of the brachiaria grasses Among grasses *Brachiaria decumbens BRA 4308* was the most productive accession during the wet and the dry periods Among legumes *Stylosanthes mineirao* and *Arachis pintoi BRA 41143* showed a higher leaf retention during the dry period compared to the *Centrosema Calopogonium and Pueraria* accessions included in the trial

The adaptation trial will continue for another year to select most promising species for crop pasture trials

1 2 Tradeoffs between crops and pastures *M Ayarza (CIAT) and L Vilela (CPAC)*

The results of our work last year showed that the establishment of legumes was markedly influenced by the crop and grass companions During the present year we planted a small plot experiment in a sandy soil of Uberlandia to investigate the effect crops (rice and corn) and several grasses on the establishment of *Stylosanthes mineirao* and *Arachis pintoi BRA 41143* Crop and pasture components were planted alone or simultaneously The experiment included a treatment of delayed sowing of the grass component to reduce early competition for the crops and the legumes Dry matter production of grasses and legumes was measured at crop harvesting

The results of the experiment with corn showed that establishment of Stylosanthes was more affected by competition from the grasses than by competition from the crop itself (Table 1) Competition from the *Panicum Vencedor* was stronger compared to the *Paspalum* species Grasses also reduced corn yields by 7% (Table 2) In turn yield potential of the pasture species were reduced by the crop (Table 3) Delayed planting of the grasses suppressed the competition effects of the grass but retarded its establishment (Table 4)

Table 1 Effect of the crop and grass components on the establishment of two forage legumes in an improved crop pasture system planted in a sandy latossol of Uberlândia MG

Treatments	Grass components			
	Vencedor /*Arachis*	***Paspalum* /*Arachis***	**Vencedor /Mineirão**	***Paspalum* /Mineirão**
		kg/ha		
Legume + corn	453	686	1710	1919
Legume + grass	158	309	2	341
Legume + grass + corn	96	221	11	144
Grass planted 30 days after legume and corn	545	618	723	1078
Tukey value (5%)				
within columns 306				
within rows 427				

Table 2 Effect of grass and legume components on corn grain yields in a crop pasture system planted in a sandy latossol of Uberlândia MG

Systems	**Grain (kg/ha)**	**Yield reduction (kg/ha)**
Corn	6364	
Corn + forage legumes[1]	6400	
Corn + grasses[2]	5837	527
Corn + legumes + grasses	5586	778
Corn + legumes + grasses 30 days after	6484	
Tukey value (5%)	964	

1/Legumes *Stylosanthes guianensis* cv Mineirão and *Arachis pintoi*
2/Grasses *Panicum maximum* cv Vencedor and *Paspalum atratum*

Table 3 Effect of several strategies of planting grasses and legumes with corn on D M production of the pasture components in a sandy latossol of Uberlândia MG

Systems	Pastures			
	Vencedor + *Arachis*	***Paspalum* + *Arachis***	**Vencedor + Mineirão**	***Paspalum* + Mineirão**
	kg/ha			
Legume + grass	15130	14055	16789	13843
Legume + grass + corn	6257	2417	4949	2526
Legume + corn	453	686	1710	1919
Grass + Corn	5965	2128	6111	2221
Grass planted 30 days after legume and corn	1157	917	1721	1287
Tukey value(5%)				
within columns 2997				
within rows 3029				

Table 4 Effect of grass species and sowing date on grain yield and forage production of a rice pasture system planted in a sandy latossol of Uberlandia MG

Systems	**Rice**		**Pasture**	
	Sowing dates of the pasture		**Sowing dates**	
	Simultaneous	**30 days after**	**Simultaneous**	**30 days after rice**
	kg/ha			
Rice + *Paspalum* + Mineirao	1106	2189	4808	628
Rice + Vencedor + Mineirao	194	2156	7458	1417
Rice + Marandu + Mineirao	1208	2556	7299	747
Rice + *Paspalum* + *Arachis*	1014	2445	5677	1988
Rice + Vencedor + *Arachis*	314	2203	7616	2733
Rice + Marandu + *Arachis*	1023	2570	6187	1612
Rice alone	2666	2437		
Tukey(5%)				
within columns	2094		842	
within rows	2854		952	

Grass competition was stronger for the rice crop than for corn crop Grain yields were reduced 50 80% depending on the species *P Vencedor* and *B brizantha* were the most aggressive species *Stylosanthes* and *Arachis* established very well with most pasture species except P Vencedor Delayed planting of grasses had the same effects observed in corn experiment

These results indicate that there are production tradeoffs in crop pasture systems and that there is a need to reduce grass competition and select more aggressive legumes for corn pasture rotations in high input systems

1 3 Multiplication of promising pasture species *(Univ Fed Uberlandia M Ayarza and E A Pizarro)*

Lack of enough seed is always a major barrier for the testing of promising forage components in large plots at the farm level To overcome this problem we made efforts during the present year to promote seed multiplication by farmers and regional Institutions of Uberlandia One ha of Stylosanthes mineirao was planted in 1993 in one of the collaborating farms Part of the seed collected this year was delivered to the University of Uberlandia and several farmers to plant multiplication plots As a result of this four ha of Stylosanthes one ha of Arachis pintoi and 500 m2 of Paspalum atratum BRA 9610 have already been established during the present year Seed produced will be purchased by the Section to expand on farm testing to other production systems and to support research activities of CIAT and EMBRAPA in other areas Remained seed will be put in the market by the University

CONCLUSIONS AND WORK PLAN

Stylosanthes guianensis cv Mineirao and *Arachis pintoi* have the potential to become components of improved rice pasture systems in a short time Enough seed will be available for further testing by farmers in the region in coming years if the collaborative effort we are developing with farmers and the university proves to be successful In the mean time we will continue our activities to select forage legumes for intensive management systems and expand testing of improved germplasm for other purposes (improved feeding for milk production cover crop and not till systems) Technology adjustment to reduce grass competition in crop pasture systems is expected to be conducted by the collaborating institutions

2 Synergism and tradeoffs of crop pasture integration

Management practices such as land preparation liming and fertilization and animal management influence the potential contribution of crops and pastures in integrated crop pasture production systems To measure these effects a long term experiment was established in a red dark Latossol at EMBRAPA CPAC in Planaltina Brazil in 1991 The objective of the experiment is to determine the effect of integration on crop and animal productivity and to identify soil key parameters related to improvement or degradation The experiments includes continuous crop and pasture systems and crop pasture and pasture crop rotations cycles of five years Land preparation methods evaluate the effect of disking (conventional land preparation) and deeper land preparation methods (flexible land preparation method) on crop productivity and soil physical properties Fertilization treatments included the effect of conventional fertilization and a corrective fertilization including the use of gypsum on crop and pasture productivity and soil fertility Grazing management treatments evaluate the effect of low and high grazing intensities on animal production botanical composition and litter production in grass only and grass legume pastures

Measurements are taken by a group of researchers from CIAT CPAC and the Universities of Bayreuth (Germany) and Cornell (USA) We are monitoring the short and long term changes in crop and animal productivity and on soil chemical physical and biological properties in the management treatments included in the experiment

The experiment is complemented with satellite plots located in several farms in Uberlandia These plots were established in 1992 on sandy and clay soil types and two production systems (continuous pastures and continuous cropping systems)to determine the potential contribution of forage legumes to improve sustainability of crop pasture systems We are monitoring changes in animal production and soil fertility in the improved and the unreclaimed systems over time Below are reported the results of the work

PROJECT TC 03 DYNAMICS OF LAND USE

Miguel A Ayarza (TL)

INTRODUCTION

Land use in the cerrado region has been extraordinarily dynamic during the las three decades Its patterns have been altered continually by government policies fiscal incentives disturbance of natural environments and introduction of new crops and technologies These patterns have not been systematically characterized and neither the reasons for rates and directions of change well understood To contribute to the lasting productivity of savanna ecosystems it is important to understand the impact of human activities on the resource base and consequently formulate appropriate policies and technologies

PURPOSE

1 Understand the dynamics of land use
2 Asses the impact of new technologies on land use
3 Appraise policy alternatives for improved land use

OUTPUTS

1 Georeferenced data bases on the spatial and temporal dynamics of land use
2 Typologies of land use classes to help to identify domains of extrapolation
3 Dynamic and multiple objective models to asses the economical and ecological impacts of land use

ACTIVITIES

During the last three years several activities were conducted to characterize the dynamics of land use in the cerrado region and select representative study areas to conduct detailed studies The operational strategy consisted in the broad classification of the region in mayor zones followed by a more detailed characterization of several representative areas This report summarizes the contribution of many members from CIAT EMBRAPA and NGO organizations working in Brazil Below are described the main activities Methodologies followed and the main results The list of publications can be found in appendix 1

1 Dynamics of Settlement and Agriculture in Brazil s Forest Margins and Savanna Ecosystems

This activity was conducted by the Instituto de Sociedade Populacao e Natureza (ISPN) under a short term contract with CIAT in 1991 The procedure consisted in the zoning of the two regions using EMBRAPA map of Brazil s vegetation and superimpose upon it a map with the same scale information containing the country s state and microregional subdivision Information was collected from the censuses from 1970 to 1985 and the preliminary results of the 1991 demographic census

The study showed that the occupation of the cerrados started spontaneously in the 1960s However important changes occurred during the economic expansion of Brazil between 1960 and 1980 A combination of federal policies high inflation and speculation were the factors responsible for the very significant increases in area and agricultural prices in the cerrados The growth of domestic and foreign markets and the gradual expansion of transportation also played a fundamental role in the agricultural expansion and modernization

The analysis of available information allowed to distinguish four zones in the region 1) a zone dynamic using modern technology and a dynamic agricultural system encompassing most of the south of the cerrados (Mato Groso do Sul Minas Gerais Goias and part of Mato Groso) 2) a fairly new area with low agricultural intensity but high technical levels around Brasilia and the west of Minas Gerais 3) an area of recent agricultural expansion with low agriculture intensity and 4) an almost empty area where agriculture is still incipient and have low technical levels These are remote areas in which conditions for expansion of commercial agriculture is still precarious

2 Area classification and mapping for the Cerrado region of Brazil

This study was carried out in 1992 by P Jones and his team with the collaboration of J Macedo and B Pinheiro from EMBRAPA The objective of the work was to subdivide the cerrado region into distinctive agroecological classes Soils climate and land use data were combined using the GIS facilities at CIAT Twelve areas were selected by f EMBRAPA as the most interesting areas to conduct collaborative research on resource management The role of CIAT was to describe the agroecological classes present in each area and identify their size in other areas within the cerrado region

The work allowed to divide the cerrado region into eleven agroecological classes and to rank the 12 areas of interest according to the number of classes and the and the area covered by each class Gurupi Campo grande Goiania Paracatu Uberlandia and Rio Verde were listed as the most representative areas

3 Socioeconomical characterization of four regions of the cerrado

This activity consisted in the analysis of the socioeconomic information of four regions of the Brazilian cerrados (Campo Grande Uberlandia Rondonopolis and Rio Verde) These areas were designated as having high priority within the EMBRAPA/CIAT project to develop sustainable land use systems The work was conducted by L Rivas from CIAT and G Pereira from EMBRAPA They analyzed the similitudes and differences between regions using information about trends on land inventory and use crop and livestock production mechanization infrastructure

There were found large differences in land use intensity farm size and infrastructure among the four regions Campo grande has most of the three fourths of its area in extensive cattle raising activities Rio verde and Rondonopolis have the largest agricultural areas and Uberlandia the lower average farm size higher intensification levels and better capacity of storage of grain at the farm level

4 Identification of land use patterns and problems

In order to characterize the main production systems detect trends of integration and identify problems and demands for technology two short term visits were carried out in 1991 and 1993 by a multidisciplinary team composed by scientists from EMBRAPA and CIAT The methodology used in the visits was the Rapid Rural Appraisal The visit included interviews with farmers and local institutions to account for the problems and research demands from the farmer perspective

The trips across the cerrados allowed to observe a consisted relationship between landscape and production systems Annual cropping systems with high use of inputs and technology are present in the flat areas (chapadoes) of medium to high clay content while extensive livestock systems are dominant on gently sloping lands over more fragile soils Although average farm size lie between 500 1000 has there are a significant number of small farms located on higher base status soils on sloping landscapes They produce most of the milk in the cerrados All production systems have problems of biophysic and socioeconomic sustainability

WORK PLAN

The information generated so far by the project has led to develop an objective classification of the cerrado agroecosystem in several classes and the selection of the Uberlandia region (M G) a case study area for detailed studies on land use dynamics and development of prototype sustainable systems However to achieve the main objectives and to develop the outputs proposed by the project it is necessary to improve the current agroecological classification and to strength our understanding on socioeconomic and ecologic impact of land use in the cerrados The following are the activities planned for the next three years

1 **Improvement of the agroecological classification system** *P Jones B Bell (LM) J Smith and M Ayarza (TL)*

This activity will include the refinement of the current agroecological classification systems and a ground truth verification of agroecological classes across the cerrado region Most recent information will be incorporated into the current database to improve the precision on the agroecological classes Field visits to selected regions of the cerrados will allow to determine the consistency of the classification

2 **Evolution of farming and regional systems and impact of land use on the environment** *J Smith (TL) W Doppler (U Hohenheim) and M Ayarza (TL)*

The objective of this activity will be to generate basic knowledge on the dynamics and sustainability of current production systems in the cerrados and to provide tools for assessing the possible future impact of improved technology marketing and policies Through this approach it will be possible to generate hypothesis pertaining the development of sustainable systems and identify research and policy measures for successful implementation of sustainable farming systems This initiative has been presented as a joint project between CIAT and the University of Hohenheim (Germany) for funding by BMZ

3 **Validation of dynamic models to asses the economic and ecologic impact of land use** *J Smith (TL)*

This activity consider the testing and validation of holistic models encompassing economic ecologic and social interactions for the development of sustainable systems Some of these models have already been developed However it is necessary to test their usefulness for the conditions of the cerrados Available information from selected production systems will be used to test the models and to adjust parameters

SUBPROJECT TC51 SOIL INDICATORS OF SUSTAINABLE AGROPASTORAL SYSTEMS

M A Ayarza (TL)

INTRODUCTION

There is evidence that some existing cropping systems in the savannas of Latin America are not sustainable either in biophysical or economic terms Soil erosion compaction and general low levels of fertility limit agricultural production on the acid soil savannas CIAT has prototype technologies combining using legume based pastures and crops which can improve soil conditions increase agricultural productivity and reverse degradation This project will determine the relationship between soil organic matter and soil physical properties in soils under different land uses

PURPOSE

Generate basic knowledge on soil physical degradation and enhancement processes and develop effective cropping systems for savanna agroecosystems

OUTPUTS

1 Quantification of the dynamics of soil organic matter in alternative cropping systems
2 Identification of indicators of degradation and enhancement
3 A conceptual model of soil physical changes in alternative production systems
4 Estimation of soil losses at the watershed level

ACTIVITIES

The project started with the arrival of two PhD students last September to conduct the work One of the students is working on the effect of land use on soil organic matter composition Soil samples were taken from several selected sites in two soil types (clay and sandy textures) in Uberlandia The selected land use systems are Continuous annual cropping systems continuous pasture systems native cerrado planted forests and crop pasture rotation systems Several techniques including 13C NMR and GC spectroscopy to will be used to identify the composition of SOM in various fractions of the soil Further studies will be conducted to determine the dynamics of most sensitive fractions in relation to soil management

The second activity is related with the water and nutrient dynamics in integrated and not integrated crop pasture systems Measurements will be carried out within our crop pasture integration experiment at CPAC Several treatments including the native cerrado and the crop and pasture systems were selected for this study The objective of the work is to study the effect of integrated and not integrated systems on water availability and dynamics of nutrients derived from organic matter mineralization (N P and S) Selected plots will be sampled over time to asses the short term effect of crop pasture rotation next year

CHAPTER IV

TA 01 PROTOTYPE SUSTAINABLE CROPPING SYSTEMS FOR FOREST MARGINS

Michael Thung CIAT/EMBRAPA/CPAF Acre

Field research activities in the Forest Margins site of Brazil begun in the second trimester of 1994 with the transfer of a cropping systems specialist to Rio Branco Acre and development of a minimal logistical infrastructure which took longer than anticipated During this initial period experiments were setup primarily in the State of Acre others in cooperation with an ICRAF senior staff located in Porto Velho Rondonia

As previously agreed with partners in the Alternatives to Slash and Burn consortium CIAT agronomic experiments concentrated initially in the introduction and testing of germplasm with the aim of identifying components for future experimentation in cropping systems In addition the cropping systems specialist participated in the characterization of the region reported elsewhere

Despite delays in developing the required infrastructure a number of experiments were conducted in the Experimental Station of CPAF/Acre and on farmer fields in the settlement project P A D Pedro Peixoto during the first semester of 1994 as follows

1 Beans regional trial for Carioca and Pink seeded grain type
2 Introduction of leading bean cultivars from southern Brazil
3 National Web Blight nursery
4 Adaptation trial of interracial crosses of beans
5 Cultural practices for reducing the web blight incidence and P fertilization

Further experiments established later in the year with various other crops are not included as yet in the present report

All nurseries in the CPAF/Acre station except the mulching experiments could not be evaluated because of the heavy web blight incidence On farmers field all nurseries were planted without fertilizer inputs Web blight incidence was milder than in the experimental station and most of the nurseries could be harvested Unfortunately there were too many missing plots due to web blight resulting in high coefficients of variation and no statistical significance

1 Results from CPAF/Acre Experimental Station

The result of the mulch experiment using Velvet bean (*Mucuna sp*) *Pueraria* sp maize residues and rice residues and 6 levels of P fertilization ranging from 0 to 400 kg P/ha can be seen in Tables 1 4 *Pueraria* gave the best protection against web blight because its leaves did not decompose as rapidly as those of velvet bean hence giving longer protection against web blight The longer the bean plants are protected from splashes of soil particles which carry the web blight spores or mycelia the higher are bean yields The highest bean yield was obtained from plots with *Pueraria* as mulch followed by rice velvet bean and the lowest yield was obtained using maize as mulch Rice and maize residue did not decompose as rapidly as velvet bean but due to low residue quantities protection against web blight was poor

Table 1 The effect of six P levels and different velvet bean management (mulch green manure and manure mixed with lime) on bean yields (kg/ha)

P level	Cover crop velvet bean			
	Mulch	Incorporated	Incorporated and limed	Mean
0	194 8	839 4	777 2	603 8
25	102 7	952 8	983 9	679 8
50	229 3	918 9	775 6	641 3
100	177 3	940 6	1006 1	708 0
200	175 8	987 8	826 1	663 2
400	191 3	941 7	642 2	591 7
Mean	178 5	930 2	835 2	648 0
CV (%)		**42 3**		
LSD (5%)		**N S**		

Plots with incorporated velvet bean produced higher yields than plots with velvet bean as mulch (Table 1) whereas incorporated *Pueraria* or maize residues were associated lower with yields than those using mulches (Table 2 and 3) The effects of mulches and of incorporation of the residues on soil parameters were evaluated but analytical results are still pending

Because of the heavy incidence of the web blight no response of P fertilization was observed although the soil was very low in P (1 6 ppm P Bray II) (Tables 1 4) Web blight decimated bean plants at random so that the response to P and N fertilization could not be evaluated (Table 5)

The 16 segregating populations now in F_8 were yield tested under irrigation during the dry season (July August) in the experiment station of CPAF/Acre *Carioca pitouco* (Carioca with growth habit 1) was used as local check All the populations tested yielded higher or at least equal to Carioca pitouco (Table 6) The number of days to flowering was reduced from 45 (in the Cerrados region) to only 33 days under the conditions encountered at CPAF/Acre Rio Branco Web blight incidence was relatively mild during the dry season (July August) using furrow irrigation This opens the possibility to produce seed of good quality in the dry season to supply the demands of the farmers in the region Currently bean seeds for the State of Acre come from as far as São Paulo

Table 2 Bean yields (kg/ha) as affected by different P levels and *Puerarıa* as mulch and green manure (incorporated before planting)

P level	**Cover crop *Puerarıa* sp**		
	Mulch	**Incorporated**	**Mean**
0	1160 0	581 3	870 7
25	1256 7	843 3	1050 0
50	1210 0	792 7	1001 4
100	1290 7	796 0	1043 4
200	1314 0	818 0	1066 0
400	961 3	466 0	713 7
Mean	1198 8	716 2	957 5
CV (%)		**34 5**	
LSD (5%)		**N S**	

Table 3 Effects of six P levels on bean yields (kg/ha) when planted on plots with maize as mulch or incorporated into the soil

P level	**Cover crop maize**		
	Mulch	**Incorporated**	**Mean**
0	308 0	385 2	346 6
25	448 7	536 7	492 7
50	395 3	378 0	386 7
100	357 3	505 3	431 3
200	365 3	292 0	328 7
400	374 7	506 0	440 4
Mean	374 9	433 9	404 4
CV (%)		**38 3**	
LSD (5%)		**N S**	

Table 4 Bean yield (kg/ha) as affected by different P levels on plots with rice residue as mulch

P level	Cover crop rice
	Yield (kg/ha)
0	834 0
25	646 7
50	749 3
100	834 0
200	906 7
400	905 3
Mean	812 3
CV (%)	**14 4**
LSD (5%)	**N S**

Table 5 The effect of N and P fertilization on bean yield (kg/ha) CPAF/Acre

N levels (kg N/ha)	P level (kg P_2O_5 P/ha)				Mean
	0 0	25 0	50 0	100 0	
0 0	682 2	811 1	1080 0	500 0	768 3
25 0	770 2	428 9	775 6	422 2	599 2
50 0	1080 0	566 7	548 9	515 6	677 8
100 0	733 3	464 4	684 4	357 8	560 0
CV (%)			**60 2**		
LSD (5%)			**N S**		

2 Results from farmers field

The regional trial for Carioca and Pink grain type on farmers field were planted in March 1994 when the rainy season was declining All advanced breeding lines tested in the region showed no adaptation problems to the hot and humid growing conditions The only difference observed was the number of days to flowering which was about 10 days shorter than in the southern regions The average yield of the tested advanced bean breeding lines was higher than the average yield of the region This may be the results of the small testing plot size which varied between 5 to 10 m^2 In the Carioca group only ESAL 588 yielded less that the check (Table 7) In general the pink advanced breeding lines yielded less than the Carioca grain types Some lines like P1 and Safira performed well in this region but the local check Rosinha yielded still higher than all the advanced breeding lines tested in this experiment

(Table 8) Several released lines from southern Brazil were tested under hot and humid growing conditions Some cultivars produced slightly higher or at least equal to the Carioca local check The Carioca cultivar multiplied in the Goiânia experiment station was out yielded by the Carioca local check (Table 9) All breeding lines that composed the National web blight nursery were out yielded by the Carioca local check and had poorer scoring in web blight resistance (Table 10)

Table 6 Yield (kg/ha) of 16 segregating population (bulk harvested) compared to the local check Carioca Pitoco (Growth habit 1) under irrigated system Planted July 7 and harvested Sept 29 1994 in CPAF/Acre Experiment Station

Ident	Yield (kg/ha)	Days to flowering	Number of pod filled	Web blight	Adaptation[1] at maturity
BZ9497	1028 4	33 0	5 0	6 0	7 0
BZ9508	1017 0	33 0	5 0	4 0	7 0
BZ9482	1006 0	33 0	6 0	6 0	7 0
GX9519	961 6	30 0	6 0	6 0	7 0
BZ9503	929 6	30 0	6 0	4 0	7 0
GX9520	927 2	35 0	6 0	7 0	6 0
BZ9513	890 2	33 0	5 0	5 0	7 0
GX9521	886 6	32 0	6 0	6 0	7 0
BZ9498	855 2	35 0	7 0	7 0	6 0
BZ9502	806 8	30 0	5 0	5 0	7 0
BZ9511	799 0	33 0	7 0	5 0	7 0
GX9522	683 2	33 0	6 0	5 0	7 0
MX9526	676 4	33 0	6 0	7 0	7 0
BZ9500	636 6	33 0	7 0	7 0	8 0
MX9514	624 4	33 0	7 0	7 0	7 0
BZ9501	607 8	33 0	6 0	6 0	8 0
CARIOCA PITOCO	599 2	30 0	7 0	7 0	7 0
CV (%)			18 3		
LSD (5%)			N S		

[1] Web blight and adaptation scoring 1 = Very good and 9 = dead

Table 7 Regional yield trial of Carioca grain type tested on farm in P A D Pedro Peixoto settlement/Acre

No	Identification	Yield (kg/ha)
1	ESAL 588	1418 8
2	CARIOCA MG	1254 7
3	AN 910518	1178 1
4	LR 720982	1173 4
5	AN 730340	1145 3
6	AN 730038	1085 9
7	AN 910236	1060 9
8	ESAL 586	1037 5
9	ESAL 579	943 8
10	AN 910523	928 1
11	LR 720982 CP	785 9
12	AN 910234	714 1
13	AN 910522	710 9
14	BZ 3815 1	415 6
	CHECK	
1	CARIOCA (LOCAL CHECK)	1329 7
CV (%)	**52 8**	
LSD (5%)	**N S**	

This first set of beans experiments show the difficulties associated with the crop in the hot and humid region where web blight constitutes the only important biotic constraint Rondônia has participated in the National Bean Evaluation Network for many years but up to the present no cultivar recommendation has been made because all the yield trials designed for the other bean growing region in Brazil could not produce reliable data A new strategy will be used for yield testing in this region To start with only the best recommended cultivars from the northern part of the Cerrado will be evaluated the plot sizes will be increased to 100 m^2 and more replicates will be included subject to seed availability Only few advanced breeding lines will enter the yield experiments which will substitute gradually the poorest lines of the experiment With this new strategy it is expected that within 2 years Acre and Rondonia will be able to recommended new cultivars In the meantime efforts by both government institutions and the private will be required to develop local seed multiplication facilities

Table 8 Regional yield trial of pink grain type tested on farm in P A D Peixoto settlement/Acre

No	Identification	Yield (kg/ha)
1	P1	1061 0
2	SAFIRA	1007 8
3	AN 730630	975 0
4	P13	975 0
5	RUBI	939 1
6	P77	895 3
7	P36	887 5
8	P80	854 7
9	P3	843 8
10	P99	796 9
11	P 71	711 0
12	FE 732325	690 7
	CHECK	
1	ROSINHA	1164 1
2	CARIOCA	1112 5
CV (%)	**34 9**	
LSD (5%)	**N S**	

Table 9 Introduction of the best cultivars from Southern Brazil compared to local check Carioca under farmers field condition in P A D Pedro Peixoto settlement/Acre

Identification	Yield (kg/ha)
ROXO 90	1330 0
JALO PREC	1107 0
NOVO JALO	1083 0
IAPAR 31	1082 0
IAPAR 16	1043 0
GOYTACAZES	1023 0
SAFIRA	922 0
CARIOCA Goiânia	845 0
APORE	807 0
EMGOPA	772 0
IAPAR 57	613 0
CHECK	
CARIOCA	1080 0
CV (%)	**21 8**
LSD (5%)	**N S**

Table 10 The National Webblight in nursery with 41 entries compared to local checks tested under farmers conditions

Number	Identification	Yield (kg/ha)	Web blight[1]
1	OURO NEGRO	775 6	7
2	MUS 80	766 7	7
3	MUS 49	753 3	8
4	MUS 52	693 3	7
5	BAT 76	624 4	8
6	ICTA 8126	604 4	7
7	RAB 27	600 0	7
8	MUS 23	591 1	7
9	XAN 112	584 4	8
10	MUS 3	582 2	8
11	BAT 67	526 7	8
12	MUS 9	524 4	8
13	TALAMANCA	522 2	8
14	BAT 1579	517 8	8
15	BAT 1449	513 3	8
16	ICTA TAMAZULAPA	502 2	7
17	MUS 21	497 8	8
18	MUS 50	491 1	8
19	LM 21303	491 1	8
20	BAT 1155	488 9	7
21	MUS 51	475 6	8
22	ICTA 8131	475 6	8
23	A 237	471 1	8
24	S 630 B	468 9	8
25	RAI 70	466 7	8
26	MUS 19	451 1	8
27	TURRIALBA 1	448 9	8

Number	Identification	Yield (kg/ha)	Web blight[1]
28	ESPARZA 9	446 7	8
29	EX RICO 23	442 2	8
30	BAT 64	442 2	8
31	ICTA QUETZAL	440 0	8
32	BAT 1297	440 0	8
33	PORRILLO 70	428 9	8
34	MUS 26	426 7	8
35	MUS 48	424 4	8
36	MUS 6	420 0	8
37	MUS 20	417 8	8
38	ICTA 8164	417 8	8
39	RAB 34	415 6	8
40	MUS 71	397 8	8
41	XAN 90	368 9	8
	CHECK		
1	ROSHINA G 2	742 2	7
2	DIAMANTE NEGRO	497 8	8
3	EMGOPA OURO	471 1	8
4	APORE	448 9	8
5	CARIOCA LOCAL	1000 0	8
CV (%)		**35 0**	
LSD (5%)		**N S**	

[1] Webblight score 1 = very good and 9 = dead

CHAPTER V

PROJECTS TL 02 AND TC 02 MECHANISTIC UNDERSTANDING AND MODELS OF SOIL CHEMICAL PHYSICAL AND BIOLOGICAL PROCESSES IN AGROPASTORAL AND SEQUENTIAL CROP PRODUCTION SYSTEMS

The purpose of projects TL02 and TC02 is to develop through the use of models a mechanistic understanding of soil chemical physical and biological processes in agropastoral and sequential cropping systems in the llanos of Colombia and cerrados of Brazil The activities pursued include the establishment of two long term experiments on station in both Colombia (with CORPOICA) and in Brazil (with EMBRAPA CPAC) NARS partners are actively involved in the development planning and execution of these experiments Crop production fertilizer optimization nutrient cycling soil properties and weed infestation form the basis of the shared activities within these experiments Work of a more strategic nature is conducted within these experiments and also within satellite experiments and is aimed at improving our understanding of key processes for sustainable production and developing indicators of sustainability Two approaches are used for sustainability indicators one is a comparative assessment determining and comparing the performance of one system with alternatives and the second approach is a dynamic one in which the dynamics of the system are a measure of its sustainability e g measuring some attribute of soil quality over time The native savannas are used as controls or benchmark sites for comparison with cropping and agropastoral systems Here we report program activities undertaken within the long term experiments together with some key process studies including nutrient cycling via litter crop residues cattle excreta and microbial biomass phosphorus transformations soil physical properties the dynamics of soil fauna populations and activities

LONG TERM EXPERIMENT 1 SUSTAINABLE CROP ROTATION AND LEY FARMING SYSTEMS FOR THE ACID SOIL SAVANNAS OF COLOMBIA (CULTICORE EXPERIMENT) *D Friesen (IFDC) H Carmen H Delgado E Owen (CORPOICA) R Thomas M Fisher A Gijsman I Rao B Volverás H F Alarcón (CIAT TL)) G Rippstein (CIAT/CIRAD EMVT) P Lavelle (ORSTOM/TSBF/Univ Paris) A Moreno J J Jiménez (Univ Complutense Madrid)*

Intensification of agricultural production on the acid soil savannas of Latin America is constrained by the lack of diversity in acid (aluminum) tolerant germplasm and poor soil fertility The use of high levels of inputs especially in monocropping situations is thought to be unsustainable since it results in deterioration of soil physical properties as well as escalation of pest problems

Improved legume based pastures considered by many as least harmful to the soil resource base require investments in inputs for establishment which are unattractive or beyond the means of extensive graziers Establishment of pastures in association with rice (to defray the cost of inputs) has proven to be a very attractive alternative which is rapidly being adopted in frontier areas of the Colombian llanos However as farmers see the profits to be made from rice this development could easily deteriorate to one of continuous monocropping with potential problems of land degradation such as those already observed with monocropping in the Brazilian cerrados Alternative systems incorporating components which attenuate or reverse the deleterious effects of monocultures are required and biophysical measures of sustainability need to be developed as predictors of system performance and health

Grain legumes green manures intercrops and leys are possible components which could increase the stability of systems involving annual crops The long term experiment described here investigates a selection of alternatives using these components at two levels of intensification based on lime and through intensive monitoring under controlled conditions to identify indicators of sustainability of rotational and agropastoral systems in the acid savannas Since many processes contribute to and interact in determining the stability of any particular system a principal objective of the project is the development of integrated models which would simulate the effects of system components and management on system sustainability as exemplified by the identified predictors and enable the evaluation and extrapolation in space and time of the effect of components and management perturbations on system stability Recognizing that the deleterious (or beneficial) effects of various agricultural practices are often subtle and only manifest themselves over long periods the proposed experimentation is intended to extend through at least two rotational cycles

MATERIALS AND METHODS

The experiment was established on a loamy clay Oxisol on the Corpoica/CIAT Research Station at Carimagua on the eastern plains of Colombia Typical of Oxisols the soil is characterized by a high degree of exchangeable Al saturation and low pH and a very low level of available nutrients (Table 3) The basic approach involves a comparison of production systems ranging from potentially resource degrading cereal monocultures to the hypothetically resource improving agropastoral ley systems all at two levels of inputs The selection of systems was based 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 fertilizer lime systems upland rice is grown in continuous monoculture or in rotations with green manures cowpeas or adapted mixed pastures while the remedial lime systems involve maize in continuous monoculture or in rotations with green manures soybeans or less adapted mixed pastures A description of the treatments is given in Table 1

The experiment is a split plot design in four randomized blocks in which levels of lime are assigned to main plots and systems to subplots Plot sizes (0 36 ha or for pastures 0 72 ha) were based on the total area required to support a minimum of three animals stocked at approximately two animals per hectare when rotated through the replications after provision for dividing at a later date Dimensions were chosen for ease of handling conventional machinery and with a view to a probable need to divide the plots in the future All systems are managed to optimize production and minimize soil degradation that is crop residue conservation is practiced soil fertility levels are maintained weeds and other pests controlled etc The experiment has been implemented in two stages rotations based on rice and low inputs of lime were initiated in May 1993 while rotations based on maize and higher levels of lime were initiated in April 1994

Sequential measurements and observations are being made of critical soil physical chemical and biological properties and the impact of changes in them on crop/system productivity and profitability resource and input use efficiency and the environment Among the observations and measurements currently being recorded are the following

Table 1 Treatment description First agropastoral cycle (five years)

Treatment No	Main Plots	Sub plots	Description
1	Fertilizer lime	Rice monoculture	Rice grown in monoculture one crop per year in the first semester second semester weedy fallow turned in with early land prepn at end of rainy season
2		Rice cowpea rotation	Rice (1st semester) and cowpea (2nd semester) in 1 year rotation residues incorporated prior to planting in following season
3		Rice green manure rotation	Rice (1st semester) and green manure (2nd semester) in 1 year rotation Legumes incorporated at maximum standing biomass levels in late rainy season
4		Native savanna (spare plot)	Managed traditionally by burning annually during dry season
5		Rice agropastoral rotation	*Brachiaria humidicola / Centrosema acutifolium / Stylosanthes capitata / Arachis pintoi* cocktail sown with rice in year 1 grazed to maintain legume content rotated every 4 or 5 years depending on pasture composition
6	Remedial Lime	Maize monoculture	Maize grown in monoculture one crop per year in the first semester second semester weedy fallow turned in with early land prepn at end of rainy season
7		Maize soybean rotation	Maize (1st semester) and soybean (2nd semester) in 1 year rotation residues incorporated prior to planting in following season
8		Maize green manure rotation	Maize (1st semester) and green manure (2nd semester) in 1 year rotation Legumes incorporated at maximum standing biomass levels in late rainy season
9		Native savanna (spare plot)	Managed traditionally by burning annually during dry season
9A		Maize soybean rotation (no till)	Maize (1st semester) and soybean (2nd semester) in 1 year rotation tillage only to initiate cropping on native savanna residues left on soil surface (no incorporation)
10		Maize agropastoral rotation	Maize monocrop in year 1 *Panicum maximum / Glycine wightii / Arachis pintoi* pasture sown with rice in year 2 grazed to maintain legume content rotated every 4 or 5 years depending on pasture composition

System and component production Grain yield and above ground biomass production are determined for crops and green manures Standing biomass feed on offer and botanical composition of pastures are assessed at three monthly intervals while root biomass production and distribution are estimated on an annual basis Records of animal stocking rates and liveweight gains (3 month intervals) are also maintained In addition the nutrient composition of crop and pasture components and green manures is measured to estimate nutrient exports and recycling through residues

Soil physical properties Parameters which are likely to reflect soil physical degradation as a result of agricultural practices are monitored annually These include bulk density porosity and water infiltration rate hydraulic conductivity and aggregate stability

Soil chemical properties Parameters are measured which are indicative of changing soil fertility loss of soil organic matter and hence soil structural stability and which permit comparisons of the relative rates of nutrient cycling in the different systems These include soil acidity and exchangeable cations and soil N P and S pools according to published fractionation procedures

Soil biology Populations and dynamics of earthworms are monitored

RESULTS AND DISCUSSION

Crop and pasture production and establishment *D Friesen (IFDC) H Carmen H Delgado (CORPOICA)*

Due to logistical difficulties the low lime input rice based systems were implemented in 1993 while the high lime input maize based systems were initiated in 1994 Average rice grain yield in the first year was about 3 t ha^{-1} and was not significantly affected by undersowing it with pasture (Table 2) Nevertheless forage species were well established at harvest and pastures were put to grazing approximately 3½ months later at the onset of the dry season (December 1993) During the subsequent 3 months animals stocked at 3 ha^{-1} gained an average of 333 g day^{-1} liveweight without placing undue pressure on the pastures which emerged for the dry season dominant in S capitata Consequently the stocking rate was increased to 4 ha^{-1} in June 1994 to try to reduce the amount of standing biomass and encourage a more balanced grass legume composition

Rice in the low input rotation systems was followed in the second semester of 1993 by an erect cowpea variety (ICA Cabecita negra) for grain production (Treatment 2 Table 1) and a prostrate cowpea variety (ICA Menegua) for green manure (Treatment 3) The green manure was incorporated at flowering 52 days after planting Cowpea grain yield was approximately 1 1 t ha^{-1} while biomass (residues) turned into the soil was approximately 1 6 t ha^{-1} for both the grain crop and the green manure (Table 2) Both residues and green manure had a marked impact on mineral N levels in the soil profile during the following dry season (see subsequent section)

Prior cropping with cowpea whether for grain or green manure production had a significant impact on the production of rice in rotation treatments in 1994 (Table 2) Rice grain yields were 300 750 kg ha^{-1} greater than in rice monoculture Part of this may be explained by the improved N economy in the legume rotation treatments alluded to above Additionally weed populations were much lower in the rotations than in the monocropped rice treatments largely because the former treatments were cultivated and cover cropped during the second semester of the previous rainy season while the rice monocrop treatment was left as a weedy fallow

The maize based systems were initiated with the acid soil tolerant material (Sikuani 3) recently released by CIMMYT Grain yields (Table 2) were low at approximately 2 5 t ha^{-1} approximately 1 t ha^{-1} less than the best obtained in satellite experiments adjacent to this experiment This disappointing performance can probably be attributed to the poor and uneven stand obtained as a result of difficulties experienced with the machinery at sowing Moreover unlike the experience with rice establishment in the preceding year where weeds were not a problem weed populations proliferated in the maize plots especially during the later growth stages We speculate that this was largely the result of the tillage operations applied in the previous year during which the entire experiment was ploughed in preparation for an anticipated complete implementation in 1993 Additionally the wide row spacing for maize may not have provided sufficient competition to weeds early in the season

Soil chemistry/fertility The unamended Oxisol under native savanna at the experiment site in characterized by a high exchangeable Al saturation low pH and low contents of available nutrients (Table 3) However exchangeable Al decreases and soil pH increases with depth in the profile below 40 cm Application of 500 kg ha^{-1} of dolomitic lime prior to implementation of the rice based systems in April 1993 did not affect exchangeable Al or soil pH (measured 4 months after application after the rice harvest) but did reduce Al saturation by about 8% as a result of increased exchangeable Ca and Mg derived from the lime An additional application of 200 kg ha^{-1} in March 1994 before sowing caused a further 8% reduction in exchangeable Al saturation (measured 3 weeks later) There was no significant effect of these amendments on soil properties at depth Phosphorus fertilizer applications (60 kg P ha^{-1} to rice and 40 kg P ha^{-1} to cowpea in 1993) increased available P from 1 5 to 6 0 ppm as measured by Bray II prior to sowing in 1994

Application of 2 t ha^{-1} of dolomite to the maize based systems reduced Al saturation to approximately 45% within 3 weeks (Table 3) Although exchangeable Al decreased and exchangeable Ca and Mg increased soil pH was only marginally affected

Levels of inorganic N in crop pasture and rotational cropping systems *D Friesen (IFDC) R Thomas (TL)*

As part of the efforts to determine nutrient balances and recycling in the experiment levels of inorganic N have been monitored in the soil profile of selected treatments during the year for use in crop models and as an assessment of nutrient use efficiency Treatments included cowpea as a grain crop and as a green manure sown in the second semester after rice The green manure was incorporated into the soil 52 days after sowing at a rate of 1 5 t DM ha^{-1} For the grain cowpea around 1 7 t DM ha^{-1} was returned to the soil after the harvest dates of Jan 5 6 1994

Soil N levels were measured in the monocrop rice rice cowpea green manure and savanna control in January 1994 Levels were low for the savanna treatment and slightly greater for soil under monocropped rice which had a marked increase in nitrate N only at a depth of 80 100 cm (Figure 1) Levels of ammonium N and especially nitrate N were greatest in the rice cowpea green manure treatment at all depths with a total of about 100 kg nitrate N ha (Figure 1) A similar trend in soil N levels was observed in early March 1994 with a marked increase in nitrate N in the rice cowpea green manure treatment of up to 135 kg nitrate N ha (Figure

2)

Table 2 Grain and dry matter production in monocultures and rotations in the long term cropping systems trial (Culticore) at Carimagua

Cultural System	1993				1994	
	Rice		Cowpea			
	Grain	Dry matter	Grain	Dry matter	Rice	Maize
	kilograms per hectare					
Monoculture					2470	
Cereal/Grain legume rotation	2850	4020[1]	1130	1720	2780	2330[1]
Cereal/Green manure rotation				1540	3120	
Agropastoral rotation	3140	4270				2570

treatments harvested as one unit per replicate

In late March levels of soil N in savanna and rice pasture treatments remained low but in all other treatments elevated levels of nitrate N were observed especially in the rice cowpea green manure treatment where up to 177 kg nitrate N ha was measured in the 1 m soil profile (Figure 3) Similarly about 113 kg nitrate N ha was measured in plots where cowpea had been grown for grain and where crop residues had been incorporated (Figure 3) Soil which had been plowed in preparation for maize sowing also had elevated levels of both ammonium N and especially nitrate N (up to 70 kg nitrate N ha) compared with undisturbed savanna soil (Figure 3) This result indicates an increased rate of N mineralization and accumulation of nitrate following soil disturbance which is in addition to the nitrate derived from cowpea green manure and cowpea residues incorporated after grain harvest

Data from September 1994 after a second successive rice crop indicate that nitrate was also present in the rice monoculture treatment after the second rice crop but at depths between 60 100 cm (Figure 4) A similar pattern was observed for the rice cowpea treatments and treatments where maize had been grown as the first crop in the higher input system (Figure 4) In comparison with the March data significant amounts of nitrate appeared lower down the profile at a depth of 60 100 cm in September compared with 0 40 cm in the monocropped rice treatment The source of this N is not known but could arise either from fertilizer applied to the second rice crop or as a result of further mineralization of soil organic matter following cultivation and land preparation procedures Unfortunately no samples were taken from the undisturbed savanna control which may have given an indication of the effect of soil disturbance on N accumulation

Table 3 Influence of lime and fertilizer inputs on soil chemical properties in rice and maize based systems

System	Depth (cm)	Org C (%)	Total N (%)	Bray P (ppm)	pH (H2O)	Exchangeable cations meq/100g Al	H	Ca	Mg	K	ECEC	Al satn (%)
Native savanna	0 10	3 24	0 14	1 5	4 51	2 35	0 31	0 25	0 11	0 09	3 11	75 6
	10 20	2 55	0 10	1 8	4 56	2 20	0 29	0 14	0 06	0 04	2 73	80 5
	20 40			1 2	4 80	1 86	0 07	0 11	0 04	0 04	2 12	87 4
	40 60			1 0	4 85	1 32	0 07	0 11	0 04	0 04	1 57	84 1
	60 80			0 9	5 13	0 93	0 04	0 11	0 04	0 03	1 15	81 1
	80 100			1 0	5 22	0 46	0 03	0 12	0 03	0 03	0 68	68 5
Rice systems[1]	0 10	3 31	0 15		4 30	2 31	0 12	0 55	0 28	0 12	3 39	68 0
(Sep 1993)	10 20	2 57	0 10		4 32	2 44	0 12	0 19	0 08	0 05	2 88	84 6
Rice systems[2]	0 10	3 08		6 7	4 18	2 00	0 24	0 56	0 37	0 19	3 36	59 6
(March 1994)	10 20	2 33		1 4	4 16	2 12	0 22	0 25	0 14	0 09	2 82	75 1
Maize systems[3]	0 10	3 13		2 0	4 44	1 54	0 19	1 06	0 62	0 11	3 52	43 9
(March 1994)	10 20	2 35		1 2	4 23	2 21	0 25	0 23	0 10	0 06	2 86	77 4

[1] after first semester rice (limed in April 1993 with 500 kg/ha dolomite and fertilized)

[2] before second year sowing (re limed with 200 kg/ha dolomite 3 weeks previously)

[3] before first year sowing (limed with 2000 kg/ha dolomite 3 weeks previously)

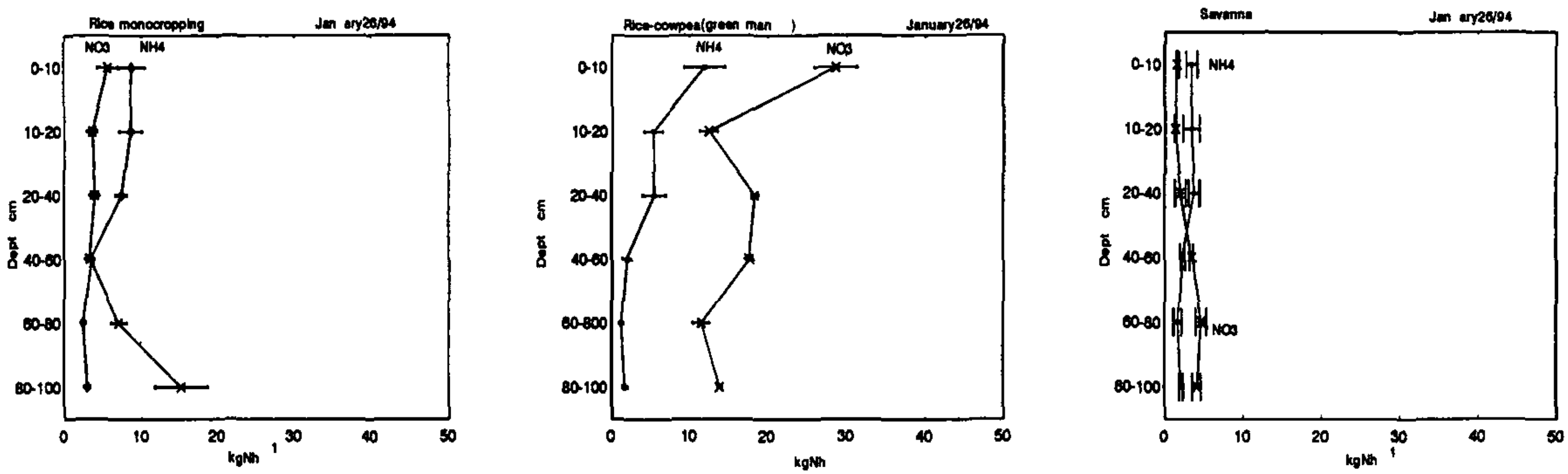


Fig 1 Soil inorganic N levels in "Culticore" experiment

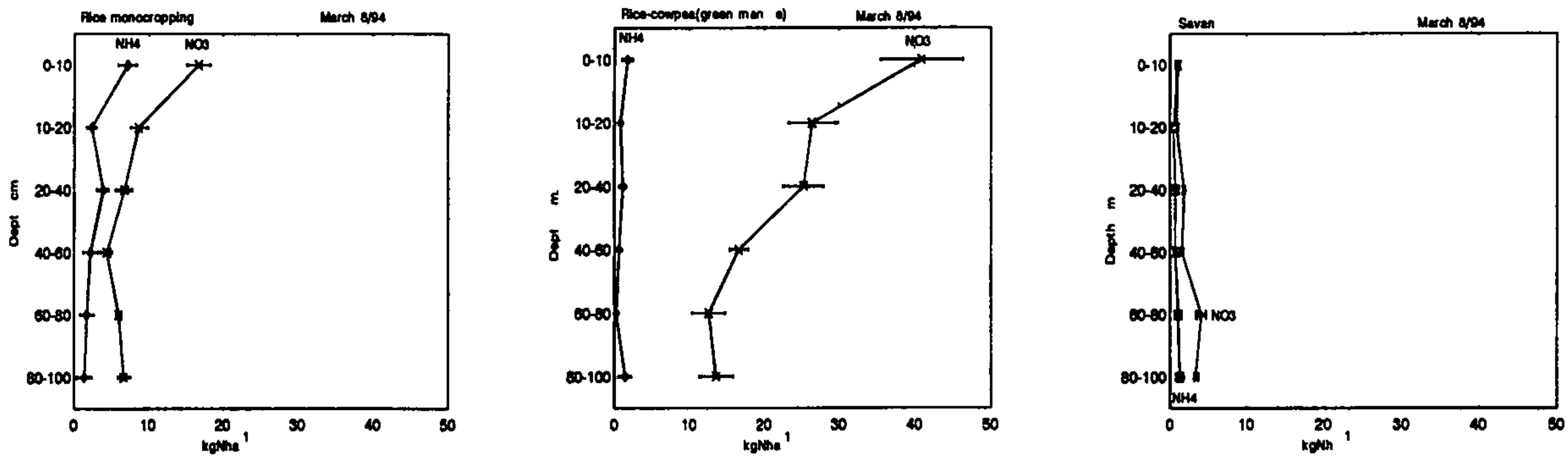


Fig 2 Soil inorganic N levels in "Culticore" experiment

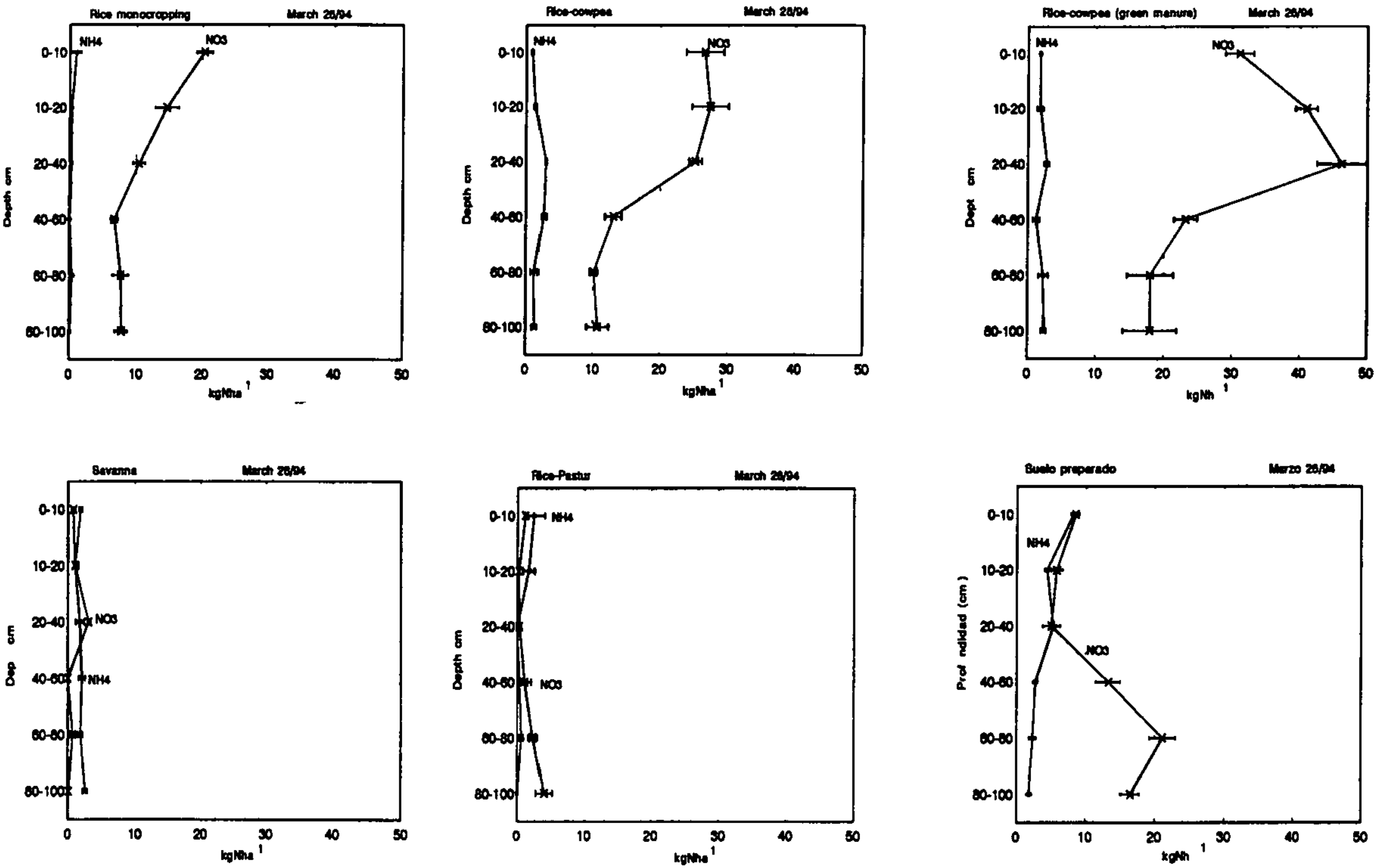


Fig 3 Soil inorganic N levels in "Culticore" experiment

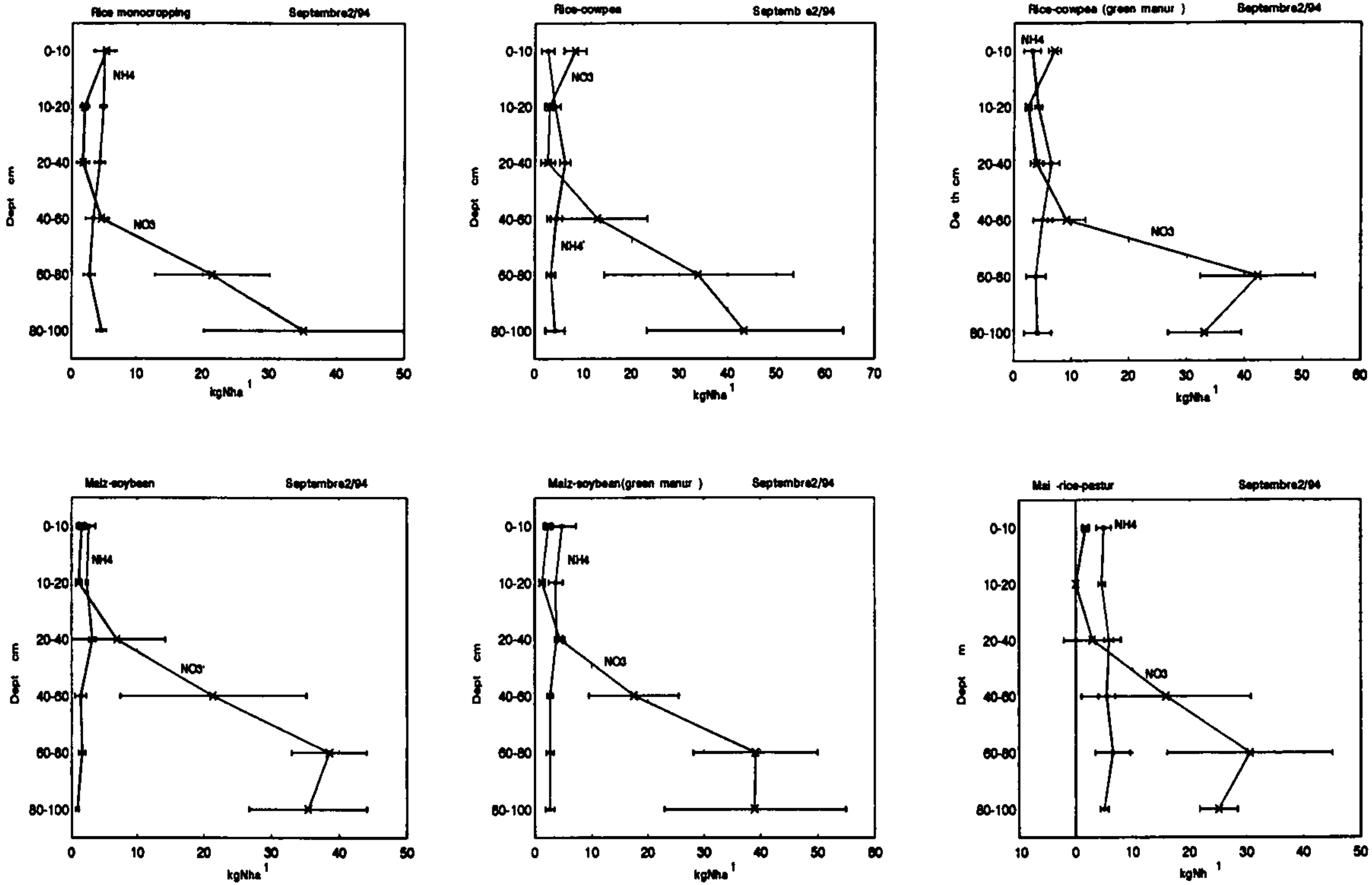


Fig 4 Soil inorganic N levels in Culticore" experiment

The data indicate the accumulation and potential leakage of large amounts of nitrate N from the cropping systems This N may be recovered if a pasture is sown simultaneously with the crop thus indicating a more efficient use of the fertilizer Further monitoring at more frequent intervals is planned for 1994/95 to gain a better understanding of the N economy of crop and crop pasture rotational systems

Decomposition of crop residues *R Thomas*

Decomposition of the crop residues in the experiment is being measured with maize rice soybean and cowpea The latter two are also being used as green manures in some treatments Previous information is available for the decomposition rates of maize (79 day half life) rice (71 day half life) and cassava (68 day half life) and nutrient release patterns (Biannual report Savanna program 1992 93) Rates of rice stubble decomposition were more than twice as great when the plant material was incorporated in litter bags in the soil at a depth of 5 10 cm compared with bags left on the soil surface (Table 4) Rice stubble left on the soil surface decomposes at a rate (0 0053 d^{1}) similar to that of either roots of the native savanna grasses (0 0056 d^{1}) or a mixture of roots and above ground litter (0 0059 d^{1}) The rice stubble in these experiments was placed in litter bags of two mesh sizes 1 and 4 mm but the rates of decomposition were identical with no effect of mesh size Therefore the data in Table 4 are presented as means of the mesh size treatments Incorporated cowpea green manure decomposed at rates greater than incorporated rice stubble (Table 4) and although the lignin N ratios were similar for cowpea (5 2) compared with rice stubble (6 8) other nutrient concentrations such as N and P were much greater in cowpea compared with rice (2 8% N 0 2% P in cowpea compared with 0 92% N and 0 08% P in rice) Studies on the decomposition of the green manure treatments (soybean and cowpea) are continuing in 1994 but results are not yet available Further discussion of these findings appears below under recycling of nutrients via decomposition of litter and crop residue

Table 4 Rates of decomposition of crop residues

Species	Treatment	K day^{1}	half life days
Rice (rice monoculture)	Superficial	0 0054 ± 0 0016	104
Rice (rice pasture)	Superficial	0 0051 ± 0 0017	108
Rice (rice monoculture)	Incorporated	0 0131 ± 0 0021	48
Cowpea (green manure)	Incorporated	0 0186 ± 0 0039	32

Mean of litter bag mesh sizes 1 and 4 mm

Effect of cropping systems on earthworm populations and distribution *J J Jiménez M Fisher*

Distribution of earthworms in the native savanna buffer area in the experiment was evaluated during November 1993 and found to have the same characteristics as in the *Brachiaria decumbens* based pastures(see below) Further measurements are being taken to document the spatial distribution of the earthworm community and to follow recolonization following cultivation with the objective of determining the mechanisms To achieve this the following contrasting treatments have been chosen and are sampled each 3 4 months

monoculture rice
Rice pasture rotation and
corn pasture rotation

The samples on each occasion are taken at the same points on a grid layout to determine the dynamics of the earthworm community across the different systems and the effects of seasonal variations These data have been not yet processed but observations at the field site indicate a very high reduction of earthworm communities which will make demonstration of spatial changes difficult

Long term experiment 2 Agropastoral systems for the cerrados of Brazil *M Ayarza (CIAT) L Vilela J C Miranda A Cardoso (EMBRAPA CPAC) H Neufeldt R Westerhof W Zech (Bayreuth University) J Duxbury (Cornell University)*

Introduction

The characterization work conducted by CIAT and EMBRAPA during the last two years highlighted the need to halt or revert soil degradation and declining soil productivity of the current production systems in the cerrados Among available technologies to increase productivity and reclaim soil fertility the combination of crops and pastures in space and time is one of the best options This technology not only increases overall productivity but also contributes to improved socioeconomic conditions of farmers Management practices such as land preparation liming and fertilization and animal management influence the potential contribution of crops and pastures in integrated crop pasture production systems In order to measure these effects a long term experiment was established in a red dark Latossol at EMBRAPA CPAC in Planaltina Brazil in 1991 The objective of the experiment is to determine the effect of integration on crop and animal productivity and to identify soil key parameters related to improvement or degradation The experiment includes continuous crop and pasture systems and crop pasture and pasture crop rotations cycles of five years Land preparation methods evaluate the effect of disking (conventional land preparation) and deeper land preparation methods (flexible land preparation method) on crop productivity and soil physical properties Fertilization treatments study the effect of conventional fertilization and a corrective fertilization including the use of gypsum on crop and pasture productivity and soil fertility Grazing management treatments evaluate the effect of low and high grazing intensities on animal production botanical composition and litter production in grass only and grass legume pastures

A group of researchers from CIAT CPAC and the Universities of Bayreuth (Germany) and Cornell (USA) is measuring the short and long term trends on crop and animal productivity and soil fertility in the experiment

The on station work is complemented by satellite plots located in several farms in Uberlandia These plots were established in 1992 on sandy and clay soil types to determine the potential contribution of forage legumes to improved sustainability of crop pasture systems in livestock production systems and in intensive management systems with annual crops Changes in animal production and soil fertility in improved and unreclaimed systems are being monitored over time Below are reported the results of the work

On Station research

1 **Crop performance** *L Vilela and M Ayarza*

After three consecutive crops results show that soil fertility management rather than land preparation methods is having a greater influence on crop yields Corrective fertilization increased corn yields by 30% compared to the conventional fertilization treatment during the present year This trend was similar to the observed with soybeans last year (Figure 5) Above ground corn biomass also increased significatively with fertilization (Table 5) The enhanced crop growth obtained in this treatment reduced weed competition which affected grain production in the conventional fertility management system *Pennisetum pedicellatum* and *Acantospermun australe* were the dominant weed species found in this system These weeds are common in annual cropping systems in the cerrados

Table 5 Effect of soil fertility and land preparation methods on performance of corn and weed biomass in the crop pasture experiment

Fertility	Land preparation	Grain (kg/ha)	Corn biomass[1] (kg/ha)	Weed biomass[2] (kg/ha)
F1	Conventional	5285 89	4577 03	2549 01
F1	Flexible	5289 90	4623 54	1972 00
	Mean	**5287 90**	**4600 28**	**2260 50**
F2	Conventional	7326 65	6545 55	1322 99
F2	Flexible	7199 10	6551 40	964 32
	Mean	**7262 87**	**6548 47**	**1143 65**

1/biomass determined at flowering time
2/biomass determined at corn harvesting time
F1 Low fertility
F2 High fertility
Conventional Disk harrow land preparation
Flexible Deep plowing land preparation

Although there were no differences in grain yield between the traditional land management system (disking) and the flexible management system (plowing) there were some differences in the distribution of corn roots with depth and on soil physical properties Measurements carried out down the 0 60 cm soil profile in several pits dug in the experiment showed an increasing mechanical resistance with depth in both land preparation methods (Figure 6) However it was greater in the 0 25 cm depth of the soil prepared with a disk (Figure 6) The use of a plough in the flexible land preparation method enhanced root growth and distribution in the 7 25 cm (Figure 7) Differences in management system due to the ameliorating effect of gypsum on subsoil acidity and calcium deficiency Although weed biomass was lower with the use of the plough differences with respect to the use of the disk were not statistically significant due to the high variability in weed population in the experiment

2 Animal performance *L Vilela and M Ayarza*

The superior animal performance in the grass legume association observed during the first year of grazing remained the same during the second year (Figure 8) *Stylosanthes mineirao* still contributed significantly to the total available forage biomass (>60%) and to the nitrogen supply to the grass via litter decomposition This resulted in a higher nitrogen content in tissue of *A gayanus* in the grass legume pasture compared to the grass only pasture (1 59 + 0 2 vs 1 13+0 01) Maintenance fertilization and grazing intensity influenced more botanical composition than animal performance Litter production data will be reported next year

A marked mortality of *Stylosanthes* plants has been observed since the last dry season (April 1994) The results of the evaluation of damage carried out at the end of the dry season indicated that 50% of the standing plants showed symptoms of a die back disease or mechanical damage produced by animal trampling Damage was lesser in *Stylosanthes* plants growing in intimate association with the grass This problem is reducing legume biomass rapidly in the experiment Therefore we delayed the initiation of grazing in the wet season and reduced grazing pressure as an attempt to maintain the legume component in the experiment

Soil physical properties under pastures followed the same pattern observed last year Mechanical resistance values in the 0 10 cm topsoil of the grazed pastures were higher compared to the cropping systems as a result of to animal trampling (Figure 9) However absolute values were below 12 mpascals that have been found to limit root growth according to previous work conducted at CPAC (Tropsoils Bulletin No 91 01) Roots of *Andropogon* were more evenly distributed in the soil profile than the corn roots and the native cerrado vegetation (Figure 10) Changes in soil chemical properties are not reported since laboratory analysis results are not available yet

3 Mycorrhiza population and activity *J C Miranda*

The aim of this work is to evaluate the effect of crops and pastures over time on mycorrhiza population and activity Propagule density (number of spores/ 50 gm soil) and activity (percentage of roots infected) is under evaluation since the beginning of the experiment Soil samples from the 0 20 cm soil depth containing fresh roots are collected three times each year (at the beginning at the peak and at the end of the rainy season) Besides spore counting a preliminary assessment of most dominant mycorrhizal genus is done in each management system Native population is low (12 spores/ 50 gm soil) and composed of several genera (*Gigaspora Scutellospora Acaulospora and Glomus*)

The results of the first year of evaluation indicated that mycorrhizal populations increased by twenty five fold during pasture establishment and by threefold under the soybean crop (Figure 11) Root colonization followed the same patterns During the second year population under pastures dropped while it increased under crops Changes are probably related to the high mycorrhizal dependence of pastures during the establishment phase and to differences in root morphology between crops and pastures

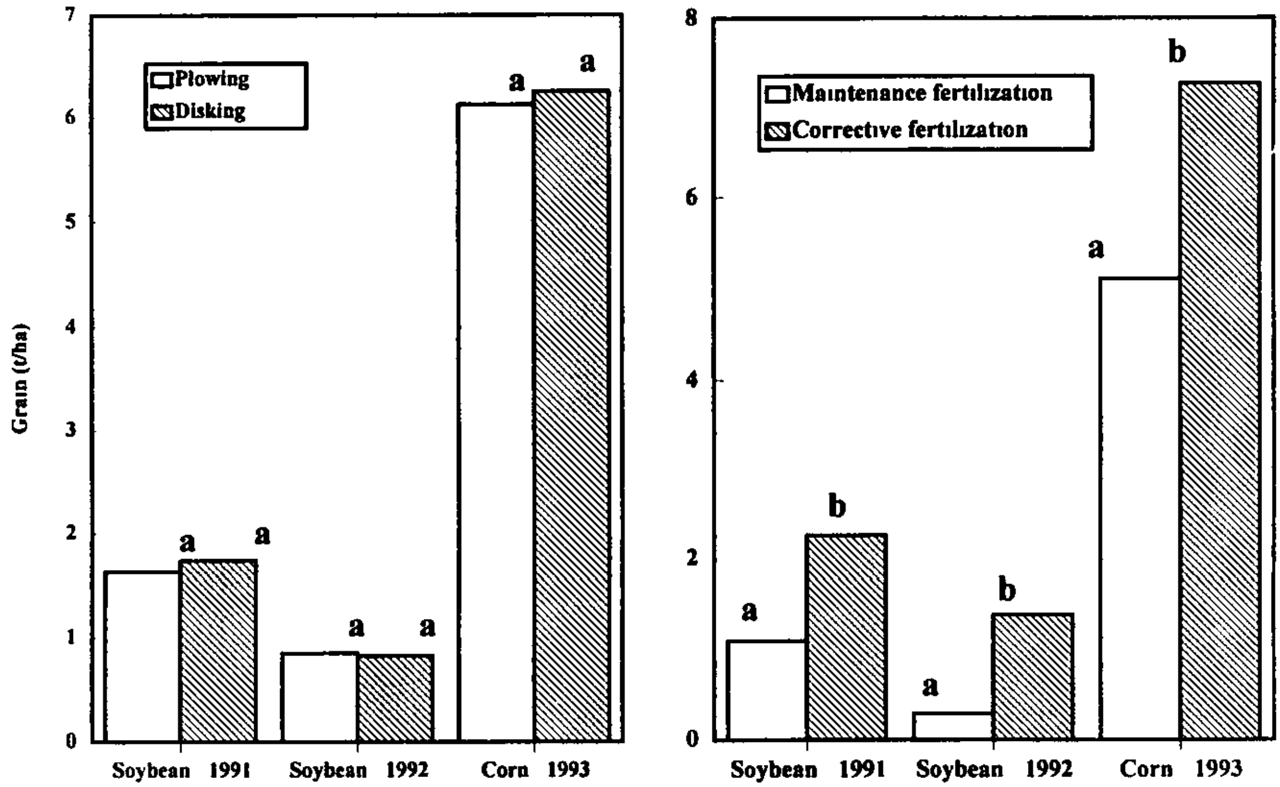


Figure 5 Effect of land preparation and two fertilization strategies on grain yields of three crops planted consecutively in dark red latossol of CPAC, Planaltina (Crop pasture integration experiment mean of two reps)

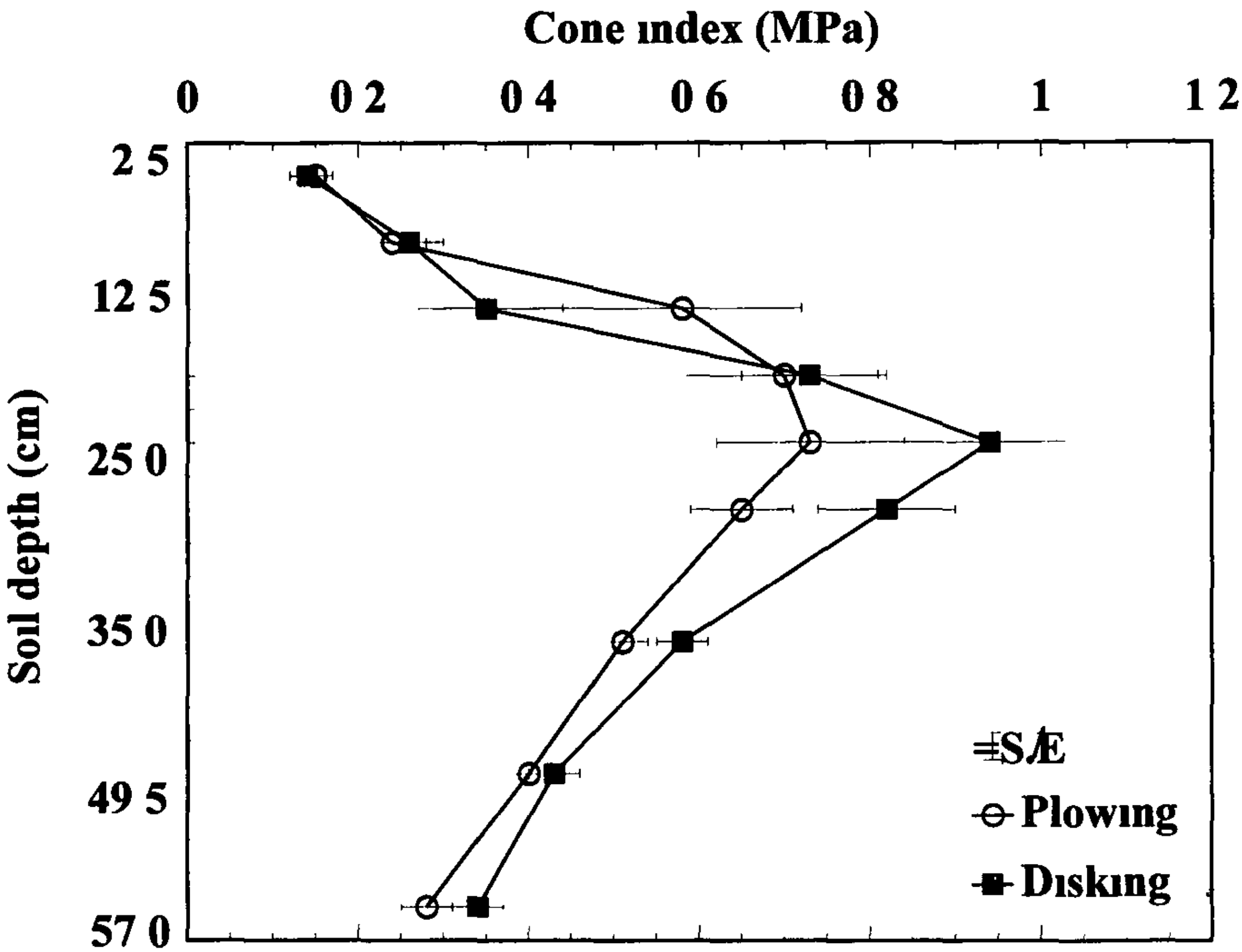


Fıgure 6 Mechanıcal ımpedance profile of thırd year effect of two tıllage treatments ıncluded ın crop-pasture ıntegratıon experıment

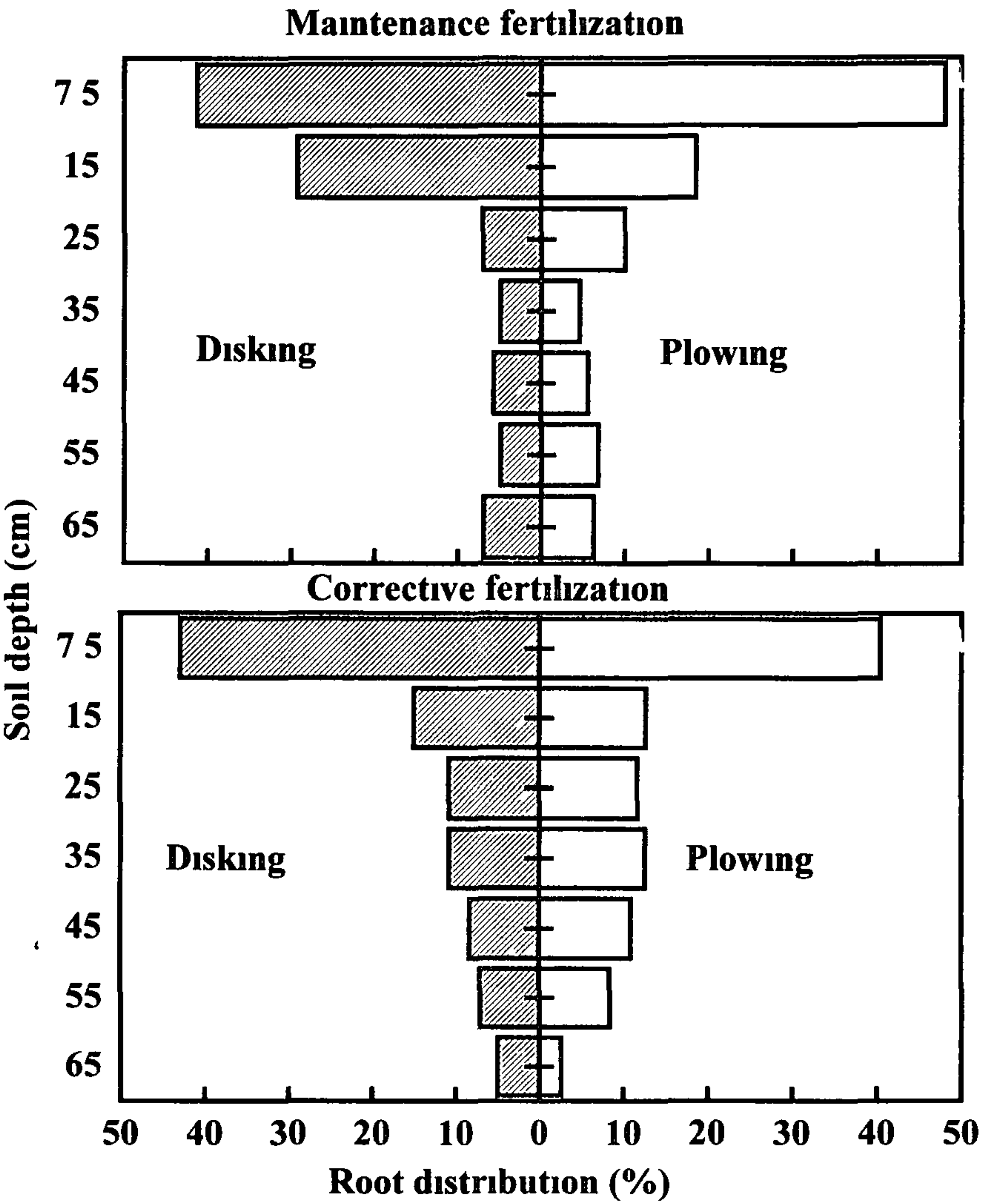


Figure 7 Corn root distribution as function of two fertilization strategies and two tillage methods (Crop-pasture integration experiment)

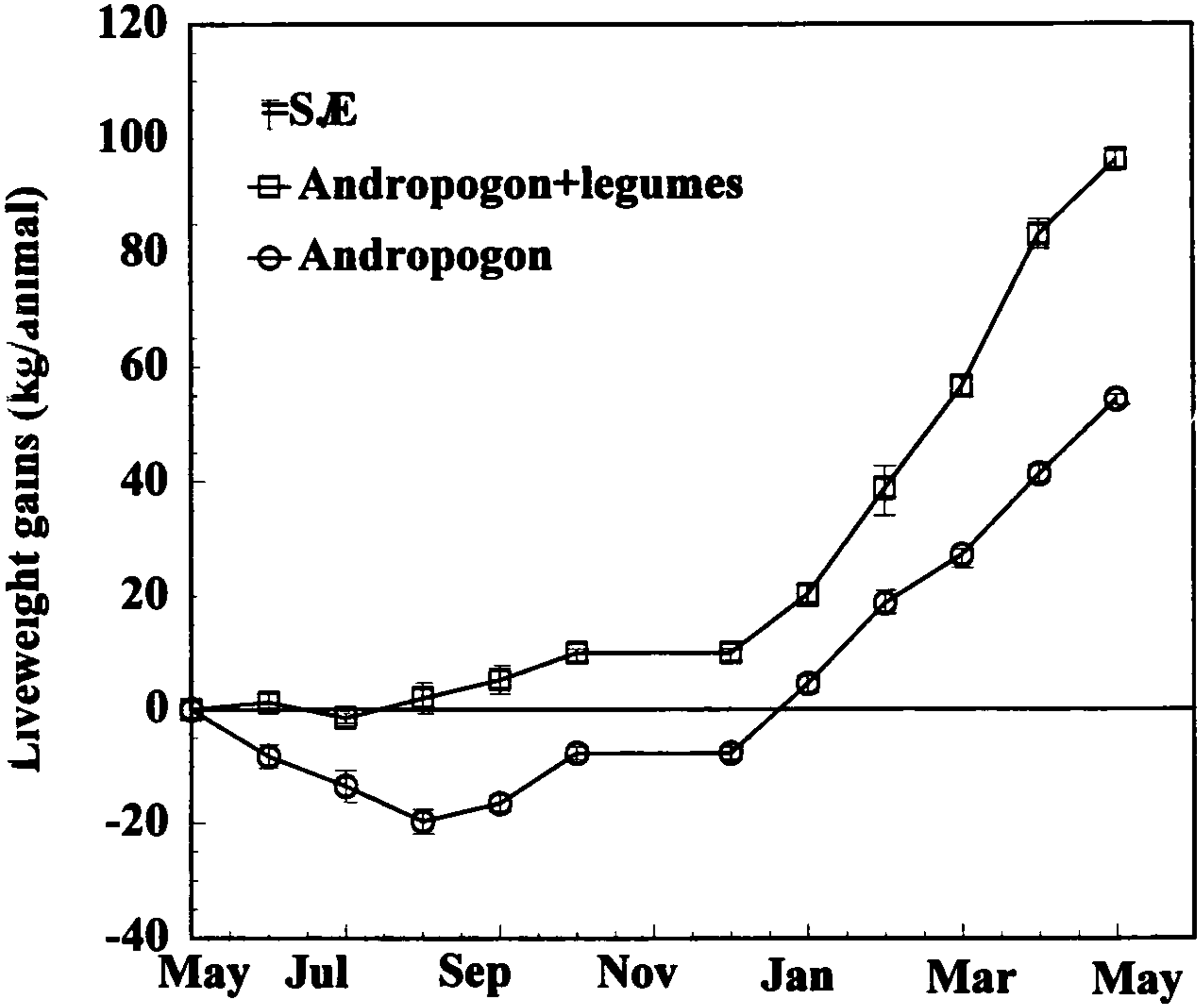


Figure 8 Liveweight gains in *Andropogon gayanus* alone and in association with a cocktail of forage legumes planted in dark red latossol of CPAC, Planaltina-DF (Crop-pasture integration experiment)

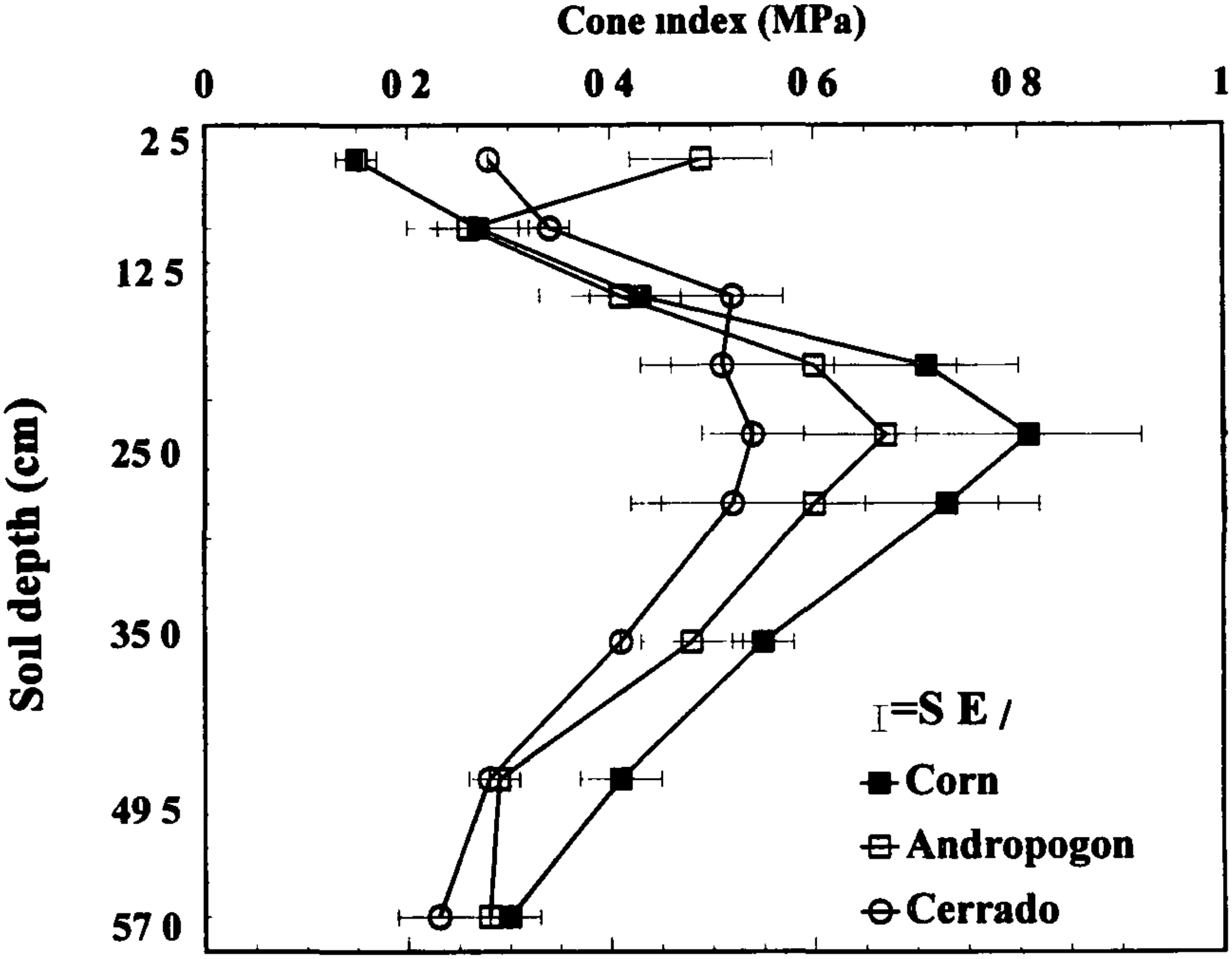


Fıgure 9 Mechanıcal ımpedance profiles of three soıl management systems ıncluded ın the crop-pasture experıment

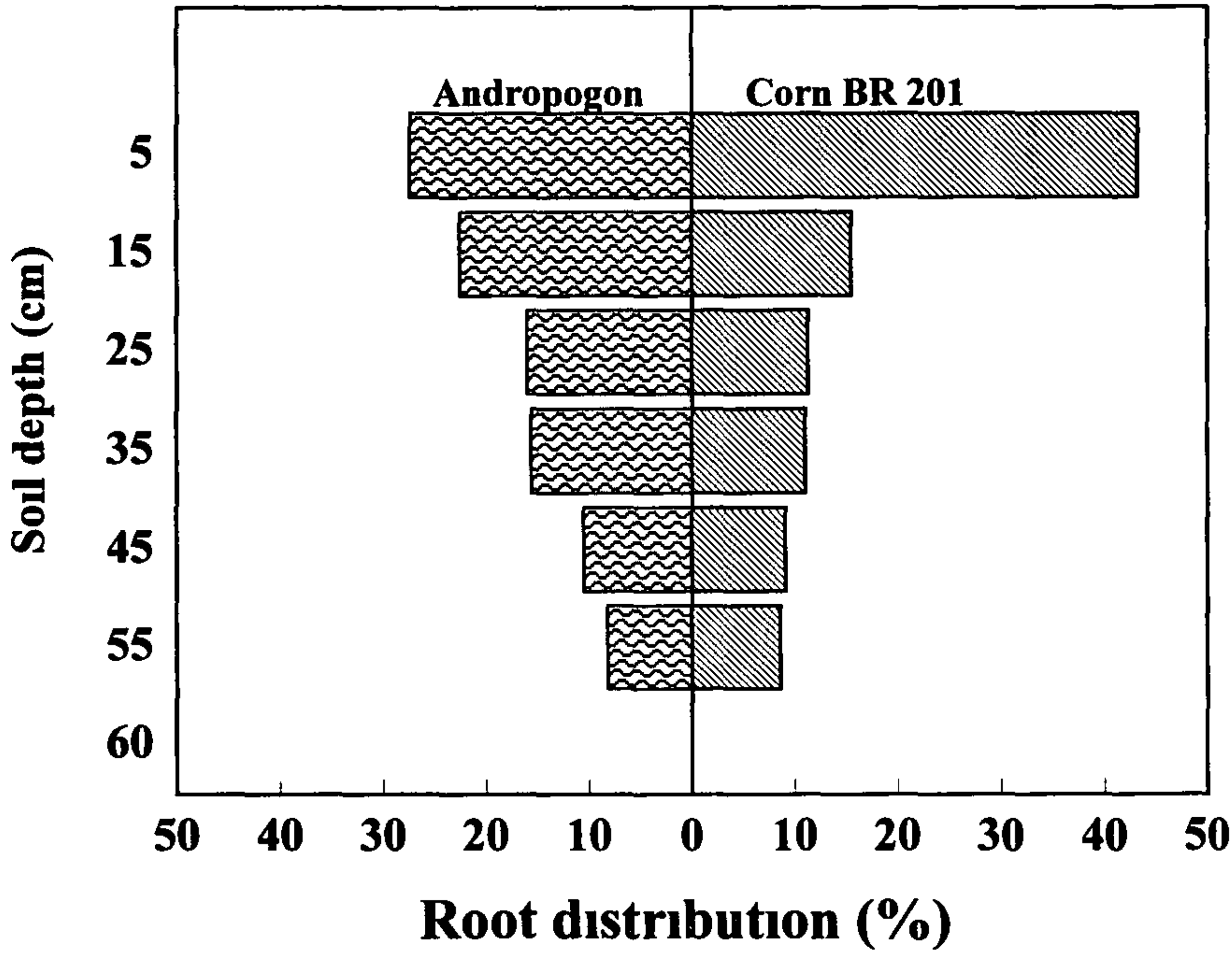


Figure 10 Relative distribution of corn and *Andropogon gayanus* roots in the 0 65 cm profile (Crop-pasture integration experiment)

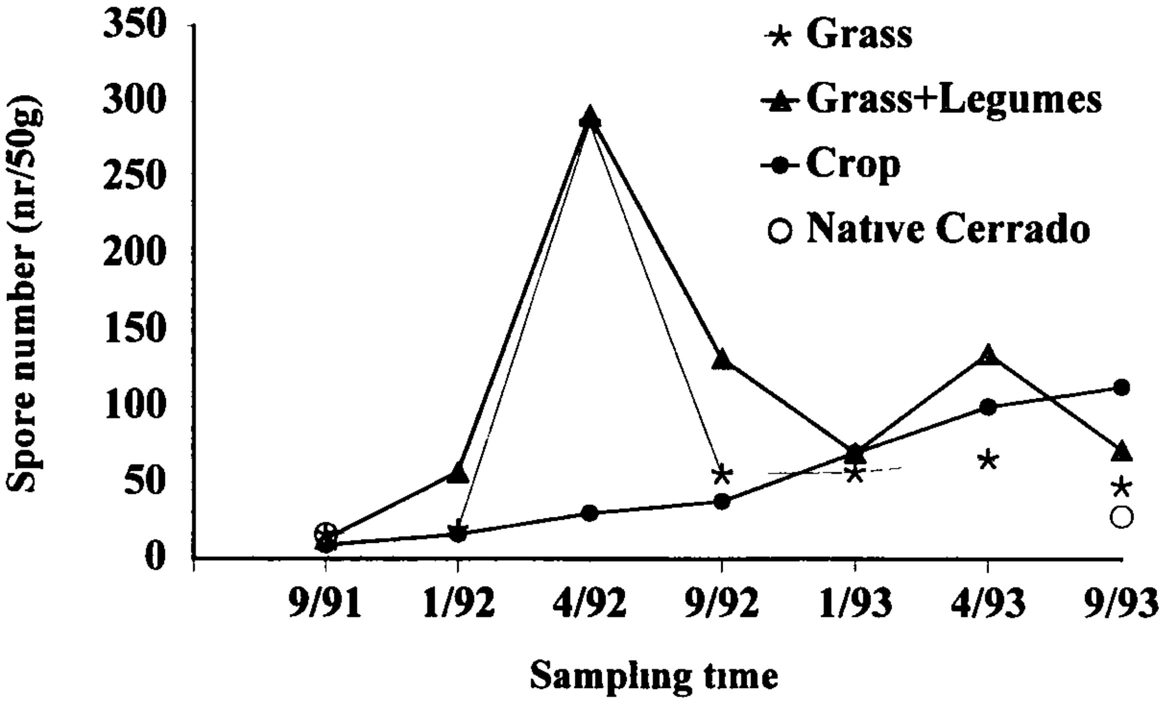


Figure 11 Variation of NVA mycorrhizal populations in a dark red latossol as a function of the management system and sampling time (Crop- pasture Int experiment)

4 Soil Organic matter dynamics (Complementary Sub project TC51) *H Neufeldt R Westerhof and W Zech*

Considerable attention is given to the role of organic matter in sustainable land use systems in neotropical savannas Besides to the beneficial effect on soil structure organic matter improves water holding capacity cation exchange capacity and soil biological activity A collaborative project between CIAT EMBRAPA CPAC and the University of Bayreuth was recently initiated to study the short and long term effects of several land management systems on soil organic composition and dynamics Two PhD students arrived last September at CPAC One is studying the long term impact of several land management systems on the composition of organic matter and the other the short term effects of land use on water and organic matter associated nutrients

The effect of land use on soil organic matter composition started with the soil sampling in several selected sites in two soil types (clay and sandy textures) in Uberlandia (M G) The selected land use systems are Continuous annual cropping systems continuous pasture systems native cerrado planted forests and crop pasture rotation systems Several techniques including 13C NMR and GC spectroscopy to will be used to identify the composition of SOM in various fractions of the soil Further studies will be conducted to determine the dynamics of most sensitive fractions in relation to soil management

Water and nutrient dynamics studies will be carried out within our crop pasture integration experiment at CPAC Several treatments including the native cerrado and the crop and pasture systems were selected for this study The objective of the work is to study the effect of integrated and not integrated systems on water availability and dynamics of nutrients derived from organic matter mineralization (N P and S) Selected plots will be sampled over time to asses the short term effect of crop pasture rotation next year

5 Effects of agricultural development on greenhouse gas fluxes in the cerrados *J Duxbury and A Cardoso*

Tropical ecosystems are globally important sources of a number of atmospheric gases including carbon monoxide nitric oxides and methane Moreover tropical land use change including both the conversion of tropical forest to pasture and agriculture and more intensive management of existing agricultural land are taking place in the tropics The impact of these land use changes on biogeochemical cycling and trace gas is not well understood

The objective of this project is to determine the influence of agriculture development on fluxes of greenhouse from/to soils of the cerrado and to learn about the processes controlling fluxes The focus of the work is on the emission of nitrous oxide and methane consumption and oxidation

Several plots from the Crop pasture experiment at CPAC were selected to conduct the study 1) native cerrado 2) continuous grass pasture 3) continuous grass legume pasture and 4) continuous annual cropping system Gas flux measurements started in July 1994 and are expected to continue for two years

Preliminary experiments using incubated soil samples from the selected plots to determine the effect of CH_4 concentration and soil moisture on methane oxidation showed a clear decrease in CH_4 concentration in the 0 60 cm soil depth in all the treatments (Figure 12)

Methane concentrations were less than 1 ppm at the 10 cm depth suggesting a strong sink for methane in the soil surface Flux measurements during a two week period showed that methane oxidation was highest in the corn plots and lowest in the cerrado plots (Figure 13) The pasture treatments were in between This results suggest that under the condition of the experiment there is not yet a reduction of the capacity of the soil to oxidize methane Increasing soil moisture decreased methane oxidation capacity in both native cerrado and corn plots However the effect was greater in the corn plots indicating that changes in pore size distribution brought about by cultivation may leave the soil less buffered in its ability to oxidize methane Nitrous oxide fluxes were very low in all management systems during the dry season However it is expected large changes during the wet season

On farm research *Miguel Ayarza and Lourival Vilela*

After several months of grazing results are showing the beneficial impact of *Stylosanthes mineirao* in improving the productivity of rice pasture systems in livestock production systems with low inputs Animal gains were consistently better in the legume based pastures than in the *Brachiaria* pasture reclaimed with rice and the original sown but degrading grass pasture (Table 6) Legumes planted with corn and *Panicum* cv Vencedor did not establish because of crop and grass competition In spite of the failure to establish the legumes the pure grass pastures are growing vigorously and supporting high carrying capacities and adequate animal gains This must be associated with the residual fertility left by several years of annual crops Evaluation of legume population in these pastures is showing a gradual increase in the *Calopogonium* and *Neonotonia* species over time in the Fazenda Sta Terezinha The evaluation of changes in soil fertility and soil physical properties under improved and unreclaimed systems started recently Results are not available yet

Conclusions

Long term controlled experiments offer the best opportunity to measure the impact of integrated crop pasture systems on production and soil fertility The experiment at CPAC allows the opportunities for the study of changes in soil chemical physical and biological parameters under a wide range of management variables

After three years of continuous cropping soil fertility management is influencing crop growth and yields more than land preparation methods Soil compaction and loss of aggregation under the conventional land preparation systems using a disk is not affecting crop performance yet Weed pressure is influenced by fertility management and land preparation methods

Satellite plots in Uberlandia are demonstrating the beneficial impact of forage legumes on animal productivity of crop pasture systems and the feasibility of including forage legumes in crop pasture rotations More than 200 farmers of the region have visited the plots

Future plans

With the initiation of the project on soil organic matter we expect to strengthen our activities on strategic research in our long term controlled experiments Contacts have already been made with the Center of Nuclear Energy at Piracicaba to study the contribution of crops and pastures to soil organic matter using stable isotopes A similar initiative is in progress with the National Center of Agrobiology at Rio de Janeiro to study the dynamics of nitrogen in crop pasture systems using ^{15}N labelling

Table 6 Animal performance on improved pastures established with crops in two contrasting management systems and soil types in several farms of Uberlândia MG

Pastures	Stocking rate (AU/ha)	Liveweight gains Animal (g/day)	Liveweight gains Area (kg/ha)
Sta Terezinha (IMS[1]) sandy soil (94 days of grazing)			
P maximum cv Vencedor[3]	2 87	483	164
Vencedor + Legumes	1 73	622	136
Bom Jardim (IMS) clay soil (99 days of grazing)			
Vencedor + legumes	2 94	655	391
Sta Inêz (ELS[2]) clay soil (118 days of grazing)			
B decumbens	1 41	641	162
B decumbens + legumes	2 09	825	299
Degraded pasture (control)		456	
Cachoeira (ELS) sandy soil (176 days of grazing)			
B ruziziensis	1 31	387	168
B ruziziensis + legumes	1 34	414	192
Degraded pasture (control)	1 28	272	142

1/ IMS = Intensive management systems with high inputs Pastures planted after several years of crops
2/ ELS = Extensive livestock systems with low inputs Pastures planted on degraded pastures
3/ Cocktail of legumes *S guianensis* cv Mineirao + *Neonotonia wightii* + *Calopogonium mucunoides*

Our current activities of monitoring of production systems in Uberlandia will be expanded to studies on pasture degradation The preliminary phase of the work will consist of the selection of the several pastures undergoing degradation and the complete characterization of their productivity and soil fertility This will be carried out by one master student from the University of Gottingen The study will be complemented with the economical evaluation of degraded pastures and improved agropastoral systems This work will be done by a second M Sc student from the same University It is expected that the pastures selected in this study can be used in the future studies assessing the impact of pasture degradation on SOM accumulation soil losses and gas fluxes

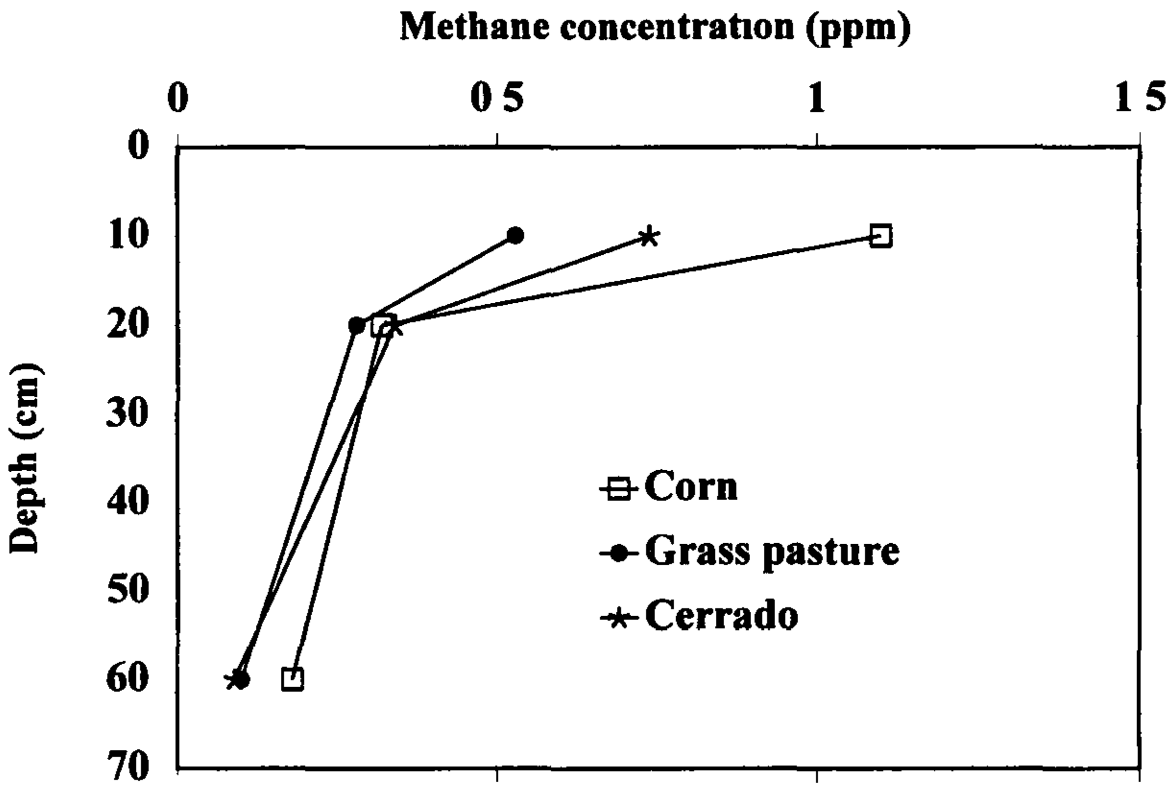


Figure 12 Soil atmosphere concentrations of CH_4 under several management systems of the crop-pasture experiment

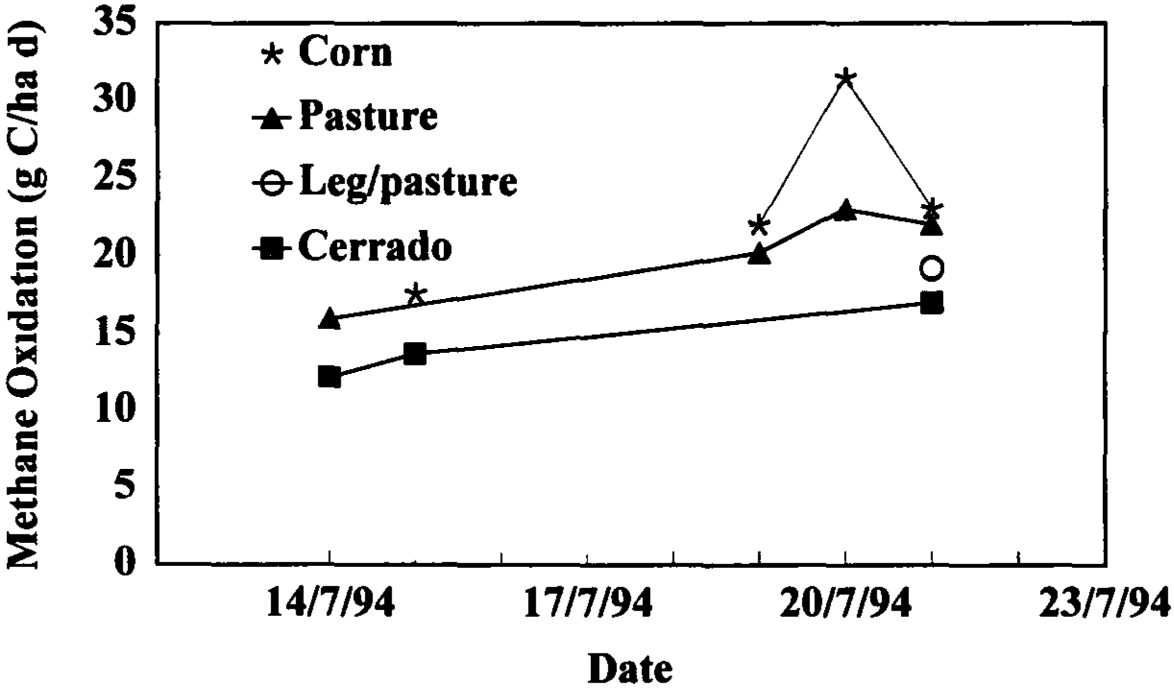


Figure 13 Methane oxidation fluxes influenced by the management systems included in the crop-pasture experiment

Recycling of nutrients via decomposition of litter and crop residue *Richard Thomas N Asakawa H F Alarcón (TL)*

Introduction

The modern view of the management of soil fertility in the tropics is one which relies more on biological processes adapts germplasm to adverse soil conditions enhances soil biological activity and optimizes nutrient cycling to minimize external inputs while maximizing the efficiency of use of any external inputs

A part of this effort will be the ability to predict the rate of release of nutrients from plant litter and crop residues by the use of models based on a sound understanding of the key processes nutrient pools and fluxes involved

In grazed tropical pastures recycling of nutrients via plant litter is probably more important than recycling via the animal when pastures are moderately grazed Crops generally receive fertilizer and their residues therefore are an important source of nutrients in low fertility soils where pools of nutrients are small and/or unavailable for plant uptake Therefore a major effort has been made to characterize the *decomposition* processes involved with both herbaceous and shrubby forages and crop litter

Decomposition of herbaceous and shrubby forages

A litter bag technique (Thomas & Asakawa 1993) was used to compare the initial composition and rates of decomposition of litter from herbaceous and shrubby legumes and one grass species with the additional treatment of litter size The latter consisted of cutting leaf litter of all species down to a size similar to that of *Stylosanthes capitata* about 10 mm length Litter bags were placed 3 cm below the soil surface in large plastic containers (50 x 30 x 25 *cm) in a* glasshouse containing an oxisol from Carimagua (clay loam from Introductions II) Table 7 shows the species used and their initial compositions As there was little or no difference between cut or intact litter the data for the two treatments were pooled (Table 8) Rates of decomposition and half lives indicated that there was a wide variation amongst the species with *A pintoi S capitata C floribunda* and *D velutinum* decomposing the fastest and *F macrophylla D ovalifolium* and *C acutifolium* the slowest (Table 8) Species with fastest rates of decomposition generally had low lignin N C N ratios or low amounts of tannins conversely species with slowest rates had high lignin N C N or high amounts of tannins when the compositional factors were considered together Lignin content (r^2 = 0 87) lignin N (r^2 = 0 67) and lignin hemicellulose ratios (r^2 = 0 68) gave the best linear correlations with k (all p<0 05)

The finding that there was little or no effect of reducing the litter size on the rates of composition of each individual species indicates that decomposition is more a function of initial composition rather than physical nature Most of the variation in decomposition rates could be explained by a combination of compositional factors such as lignin C N ratio hemicellulose and tannins

Table 7 Composition of leaf litter of shrubby and herbaceous forages

Species	CIAT Acc No	% N	% Lignin	% Tannin	% hemicellulose	L N	C N	L H
Flemingia macrophylla	17404	1 25	35 4	0 40	6 8	28 3	42 2	5 2
Cajanus cajan	21256	1 83	25 1	1 66	8 4	13 7	29 3	3 0
Cratylia floribunda	18672	1 86	26 5	0 15	17 9	14 2	26 9	1 5
Desmodium velutinum	23981	1 24	16 8	0 25	11 7	13 5	36 6	1 4
Herbaceous Legumes								
Desmodium ovalifolium	13089	0 81	36 4	3 83	14 2	44 9	55 7	2 6
Centrosema acutifolium	cv Vichada	2 57	31 2	0 06	13 5	12 1	19 3	2 3
Pueraria phaseoloides	9900	1 75	23 4	0 26	18 4	13 4	29 5	1 3
Arachis pintoi	17434	1 50	17 1	0 27	4 7	11 4	29 7	3 6
Stylosanthes capitata	cv Capica	2 09	21 9	0 12	17 0	10 5	20 2	1 3
Grass								
Brachiaria dictyoneura	6133	0 41	10 30		21 1	25 1	123 1	0 5

The litters used in this study was also examined for *in vitro* dry matter digestibility estimates (IVDMD) in collaboration with Dr C Lascano of the forages program to determine if a relationship existed between rumen liquor digestibilities and litter decomposition Such a relationship could be used as a common simple indicator for both processes even though one is anaerobic (rumen) and the other essentially aerobic (decomposition in soil) Although there was a positive trend between litter decomposition constants and estimates of IVDMD the correlation was not significant (r^2 = 0 58) These initial results suggest that there may be some merit in exploring this relationship in more detail and a joint research project has been written with the forage program

Table 8 Decomposition constants and half lives of shrubby and herbaceous forages

Species	k (d^{-1})	half life (days)
Shrubby Legumes		
F macrophylla	0 0025	196
C cajan	0 0054	93
C floribunda	0 0064	54
D velutinum	0 0077	46
Herbaceous Legumes		
D ovalifolium	0 0029	135
C acutifolium	0 0032	114
P phaseoloides	0 0078	61
A pintoi	0 0066	38
S capitata	0 0085	49
Grass		
B dictyoneura	0 0047	94

Litter decomposition in the coffee zone of Colombia

The decomposition of the leaf litter of the forage legumes *A pintoi D ovalifolium* and the tree *Leucaena leucocephala* was compared with leaf litter of coffee (*Coffea arabica*) at two sites (Naranjal and Granja) with similar soils but contrasting environments in the experimental stations of CENICAFE near Manizales Caldas Rates of decomposition were slightly greater at Granja compared with Naranjal probably due to a cooler climate at Naranjal (Table 9) The large differences in decomposition constants for *L leucocephala* are difficult to explain as the initial material was identical *A pintoi* decomposed quickly in this environment and studies are continuing on the role of this and other forage legumes as suppliers of nitrogen for coffee in collaboration with CENICAFE

Table 9 Decomposition parameters for leaf litter in the coffee zone

Site	Species	K (day ^{1})	Half life (days)
Granja			
	D ovalifolium	0 0056 ± 0019	112
	A pintoi	0 0370 ± 0043	20
	L leucocephala	0 0237 ± 0030	31
	C arabica	0 0120 ± 0010	58
Naranjal			
	D ovalifolium	0 0050 ± 0015	129
	A pintoi	0 0176 ± 0023	37
	L leucocephala	0 0057 ± 0008	120
	C arabica	0 0088 ± 0008	76

Effect of litter bag mesh size on decomposition

Litter bags of different mesh size may exclude certain soil fauna and therefore could effect the rates of decomposition To determine the extent of this effect leaf litter of different forage grasses and legumes were placed in the field at Carimagua in bags of 1 2 and 4 mm mesh size and decomposition was followed using the methodology previously described (Thomas & Asakawa 1993) A single exponential decay function was fitted to the data to calculate decomposition constants (k) and litter half lives in days The results indicated that bag mesh size had little effect on the decomposition parameters for any of the species studied (Table 10) As reported previously and above the legume *Arachis pintoi* decomposed at the fastest rates while *Desmodium ovalifolium* and the grass *Brachiaria dictyoneura* decomposed at slowest rates These results indicate the in the environment of a tropical acid soil savanna fauna which could not enter bags of mesh size 1 mm play a relatively minor role in litter decomposition This data taken together with that above and previous reports (Biannual Report Savanna Program 1992 1993) indicate that the chemical composition of tropical forage litter and crop residues is a more important regulatory factor than the decomposer organisms or physical structure of the plant material of the species studied to date

Soil inorganic nitrogen levels were measured below the positions of the litter bags in these experiments to determine whether or not levels of inorganic N were increased as litter decomposed However in no treatment was an elevated level of either nitrate or ammonium detected indicating that either decomposition was slow or that the release of any inorganic N was quickly immobilized by microbial biomass and/or plants (data not included)

Conclusions

The available data indicate that litter/crop residue composition plays a key regulating role in plant decomposition and nutrient release in tropical savannas and that the most significant regulating factor is the lignin N ratio with additional minor roles for the C N ratio and polyphenol or tannin content The latter are generally low in litter/crop residues compared with green manures where tannins have been implicated as major regulatory factors Thus it may be convenient to use the litter decomposition module in the CENTURY ecosystem model to predict rates of decomposition and nutrient release patterns for material with a wide range of lignin N ratios Earlier work has been reported which validates the usefulness of this model in such predictions (Biannual Report Savanna Program 1992 93) even though some problems have been identified in the use of CENTURY for long term soil carbon and other nutrient estimates under moist tropical savanna conditions

Table 10 Effect of litter bag mesh size on decomposition parameters

Species	Bag mesh size mm	K	half life (days)
Centrosema acutifolium	4	0 0129 ± 0 0011	50
	2	0 0048 ± 0 0015	115
	1	0 0100 ± 0 0024	59
Pueraria phaseoloides	4	0 0083 ± 0 0017	72
	2	0 0056 ± 0 0012	106
	1	0 0077 ± 0 0015	81
Arachis pintoi	4	0 0131 ± 0 0024	46
	2	0 0078 ± 0 0011	79
	1	0 0142 ± 0 0026	44
Desmodium ovalifolium	4	0 0055 ± 0 0015	102
	2	0 0045 ± 0 0008	134
	1	0 0058 ± 0 0014	104
Brachiaria dictyoneura	4	0 0063 ± 0 0016	96
	2	0 0062 ± 0 0007	102
	1	0 0061 ± 0 0012	103

Nitrogen transfer from ^{15}N labelled litter and cattle urine *Richard J Thomas N Asawaka H F Alarcón (TL)*

Plant litter and excreta from large herbivores are two of the major routes for N cycling in grazed pastures Legume N may similarly be transferred to grasses via these recycling routes In tropical pastures with improved plant species little or no information exists on these processes and data on the recovery or loss of this nitrogen from the soil plant system is particularly scarce

Litter N Plants of the forage legumes *Arachis pintoi* and *Centrosema acutifolium* were grown in washed sand in a glasshouse with a source of ^{15}N to label the plant N (ammonium sulphate 99 6% atom excess ^{15}N) Labelled leaf litter was collected from these plants and applied to four 0 1 m^2 subplots at rates equivalent to 15 g DM m^2 in a grass only pasture (*B dictyoneura*) on a clay loam soil (Intro II) of the core experiment in Carimagua The rates of N addition were 0 31 g N m^2 for *A pintoi* and 0 32 g N m^2 for *C acutifolium* Four equivalent matching subplots were used to determine the standing biomass by cutting to 5 cm height and ^{15}N enrichment of the soil at time zero Both subplots were located in each of four larger 1 m^2 plots which were protected from grazing throughout the experiment by exclusion cages

Soil (0 5 5 10 and 10 20 cm layers by depth) and grass samples were taken over time to determine the fate of the labelled N by measuring water contents dry weights total N and ^{15}N enrichments The influence of soil fauna was monitored by recording the presence or absence of activities such as ant nests or earthworm casts in the subplots

Rates of grass dry matter regrowth and N accumulation were similar with or without either of the two legume litters after 92 days The recovery of labelled ^{15}N from the legume litter 92 days after application in grass regrowth was less than 1% with *C acutifolium* and only 1 7% with *A pintoi* despite the reported rapid rates of decomposition of leaf litter of the latter species Data on ^{15}N in the soil and hence on total recovery of added N are not yet available There were no visible effects of soil or litter movements resulting from soil fauna activity

Conclusions

It is apparent that the transfer of labelled N from leaf litter of legumes to grasses is extremely slow under conditions similar to those under a grazed pasture

Cattle urine In the second experiment ^{15}N labelled urea N was added to cattle urine collected from animals grazing the grass only pastures in the core experiment at Carimagua The labelled urine was then added to 1 m^2 microplots of *B dictyoneura* in the same plots from which urine was collected at a rate equivalent to a single urination i e 2 6 l m^{-2} The amount of N applied including the labelled urea N was 3 66 g N l^{-1} or 95 16 kg N ha^{-1} The microplots were bordered with aluminum sheets to a depth of 15 cm and were protected from further grazing by cages after a taking standardization cut to 5 cm height Herbage was cut approx two times per month to a height of 5 cm until there was no visible difference in regrowth in the control (water) or urine treated plots and total dry matter N and ^{15}N enrichments were measured Soil cores were taken at intervals to a depth of 20 cm separating the cores into 0 5 5 10 and 10 20 cm layers and measurements were made for soil pH inorganic nitrogen in KCl extracts and ^{15}N enrichments of total soil N

Twelve days after urine application around 4% of the added ^{15}N label was recovered in plant regrowth and 63% was recovered in soil organic matter Around 33% was not recovered After 92 days about 10% of the labelled N was recovered in new herbage A complete analysis will be made when data for other dates are available Figure 14 shows the response of the grass to urine application After 92 days the grass receiving urine had accumulated 1 2 g N m^{-2} more than the control (12 kg N ha^{-1}) and after 155 days 82 6 g DM m^{-2} more than the control (826 kg DM ha^{-1}) The %N in herbage receiving cattle urine was as much as 0 8 %N greater than that in herbage receiving water (2 89% vs 2 08%N) with the differences decreasing with time until 92 days after application when N concentrations in herbage were similar between treatments (1 23% vs 1 16%N) Figure 14 also indicates that the differences between the treatments increased with time in terms of DM accumulation Further analysis of this data will be done when the ^{15}N labelling results are available Of particular importance will be an analysis of the fate of the large amounts of labelled N in the soil organic matter

There were little or no differences in soil pH at any depth between the urine treatment and the control This is in contrast with the work reported from temperate grasslands which indicates pH increases of up to 0 5 units in urine treated soil mainly as a result of rapid urea degradation at the soil surface

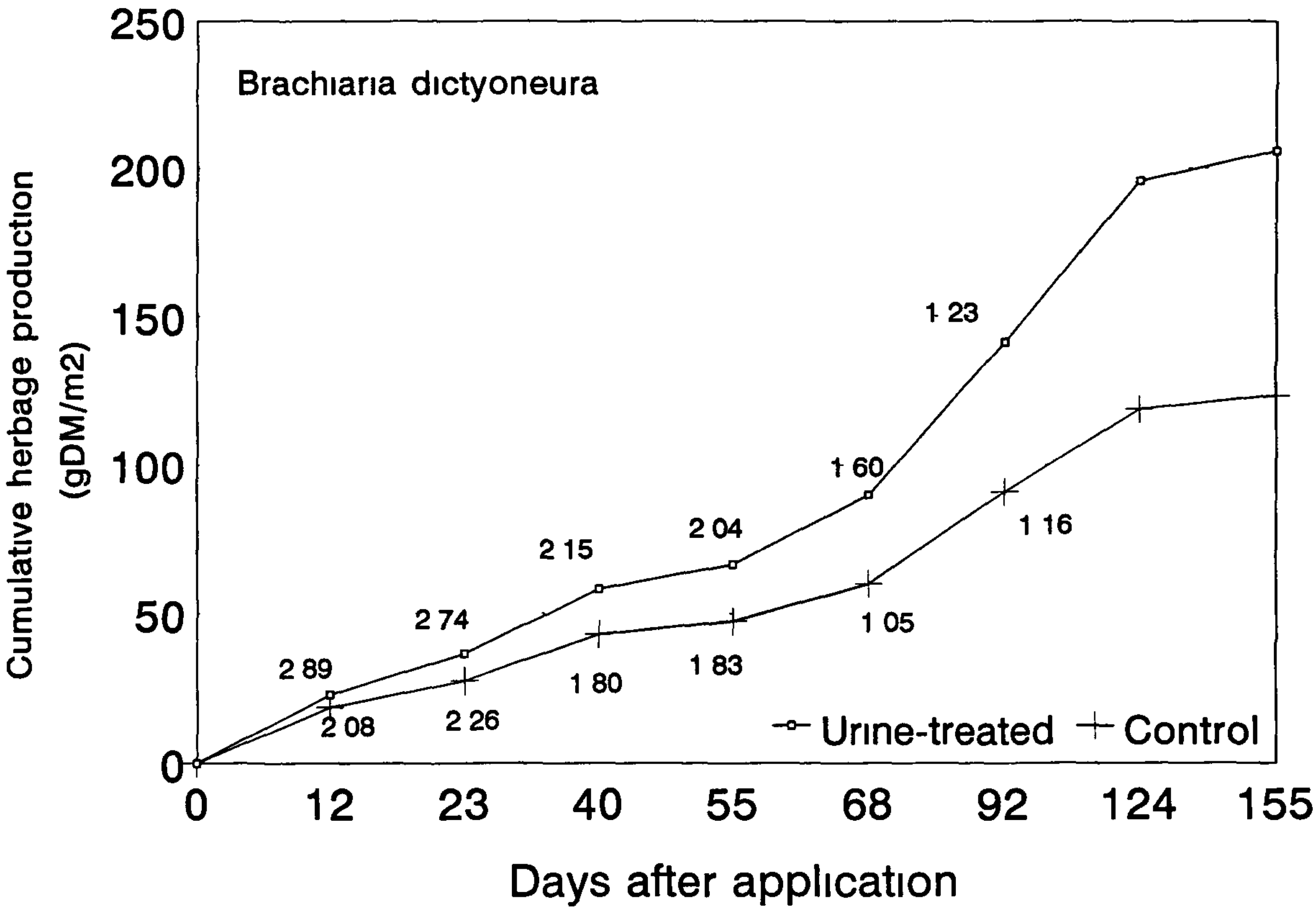


Fig 14 Response of herbage to urine application

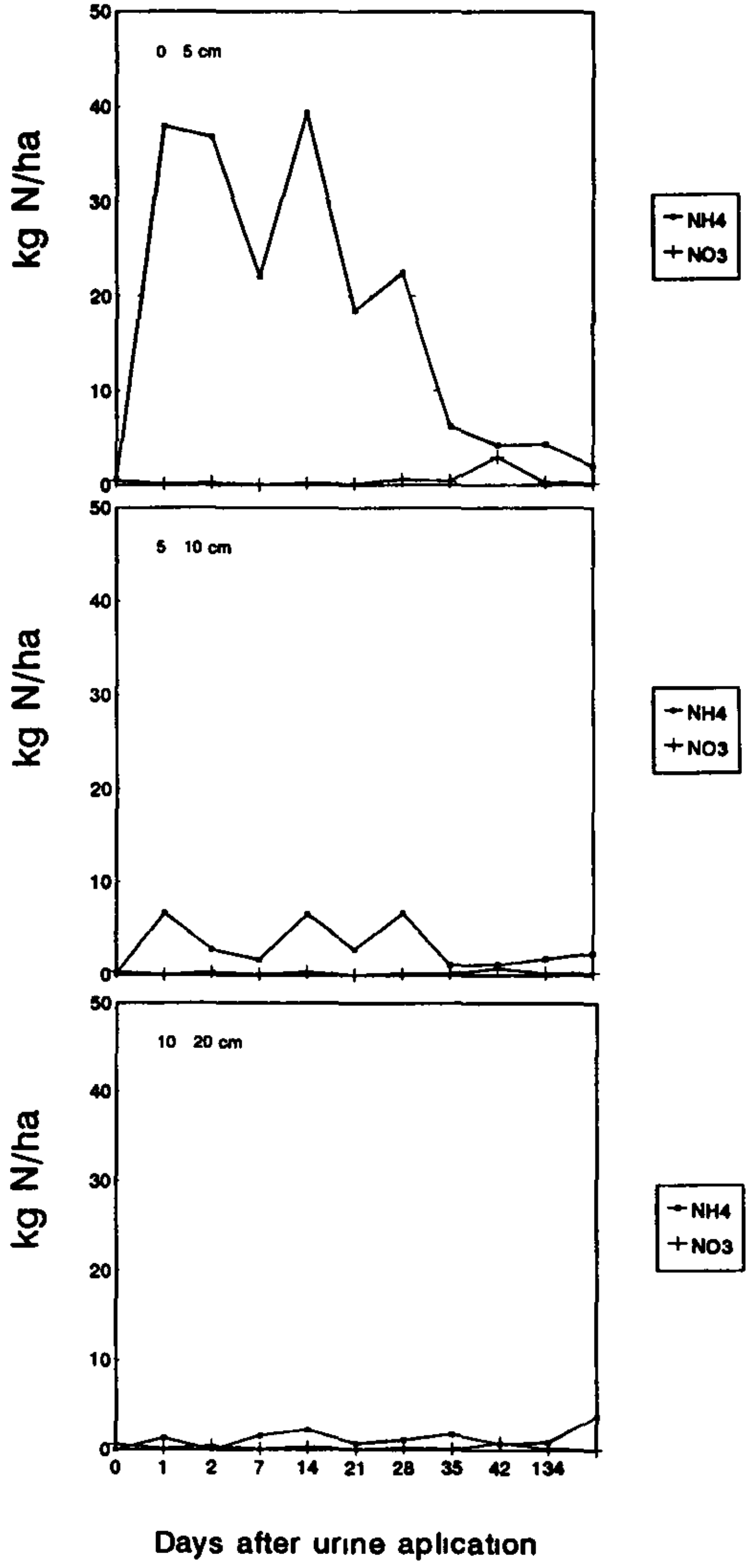


Fig 15 Inorganic N in soil after urine aplication

Levels of inorganic N (ammonium and nitrate) were monitored at 0 5 5 10 and 10 20 cm depths over time Ammonium increased in the soil immediately after application (Figure 15) and then decreased gradually over 28 days There was little or no appearance of nitrate over the 155 days monitored indicating little apparent nitrification Most of the increase in soil ammonium N levels occurred in the top 5 cm of the soil profile with little apparent movement downward (Figure 14) These results await confirmation from the ^{15}N labelling data in soil organic matter

Conclusions

The results demonstrate the faster recycling of N via animal urine than via plant litter and a greater % recovery with urine compared with litter Apparent losses of urine N were relatively low compared with data from temperate systems The data indicate that although the returns of N to the soil may be greater via litter than urine the actual amounts of N available for plant uptake may be greater from animal excreta

Phosphorus transformations in improved pastures *A Oberson (U Saskatchewan) D K Friesen (IFDC) H Tiessen J Moir (Univ of Saskatchewan) G Borrero (TL)*

Introduction

Phosphorus is among the nutrients most limiting plant production in the acid savannas Acid tolerant pasture germplasm cannot be established without additions of purchased P and there are insufficient amounts available in the unamended soils to improve recycling Improved pastures using acid tolerant grass and legume varieties have resulted in a 10 to 15 fold increase in beef production per ha in field experiments in Carimagua The fact that this dramatic production increase was obtained with modest P fertilizer inputs raises questions about the perceived inefficiency of P fertilizer inputs on high weathered high P sorbing soils and about transformations of soil and fertilizer P occurring when native savanna is replaced by improved grass only or grass legume pastures The present investigation attempts to answer these questions by means of sequential chemical P fractionation to assess the significance of different organic (P) and inorganic (P_i) P fractions and by estimated P budgets for native savanna and improved pasture soils The fractionation method was augmented with the characterization of the C/N/P ratios of the organic matter extracted during different steps Data are discussed in terms of an improved understanding of P transformations in soils under improved pastures The usefulness of different P and P fractions as sustainability indicators is evaluated

Material and Methods

Soil samples were taken in a long term pasture experiment established in 1978 on an Oxisol at the ICA CIAT Carimagua research station in the eastern plains of Colombia Treatments included were native savanna (SA) grass only pasture (GO) (*Brachiaria decumbens* cv Basilisk) and grass legume pasture (GL) (*Brachiaria decumbens* cv Basilisk with *Pueraria phaseoloides* CIAT 9900 (Kudzu)) Different P and P fractions were sequentially determined using the following extractants H_2O with anion exchange resin 0 5 *M* $NaHCO_3$ 0 1 *M* NaOH 1 0 *M* HCl hot conc HCl The soil remaining at the end was digested with perchloric acid to assess residual P Inorganic P in extracts was determined by the molybdate ascorbic acid method Total P in the H_2O $NaHCO_3$ NaOH and hot HCl extracts was measured after digestion with $K_2S_2O_8$ Organic P was calculated as the difference between total P and P Fractions are abbreviated as follows H_2O P Resin P Bic P P NaOH P P HCl P HCl_h P P Resid P_t Organic C in H_2O $NaHCO_3$ NaOH and HCl_h extracts was determined using a modified $K_2Cr_2O_7$ H_2SO_4 method Total N in H_2O $NaHCO_3$ and NaOH extracts was determined by digestion with $K_2S_2O_8$ in an autoclave Total N in the HCl_h extracts was determined after Kjeldahl digestion on an autoanalyser

RESULTS AND DISCUSSION

Effects of improved pastures on organic and inorganic soil P fractions

While both P and P fractions were affected by improved pasture treatments (Table 11) the GL pasture induced more pronounced changes than the GO pasture when compared to the SA This was a consequence of the overall significantly higher total P (SumPT and PT Table 11) content of the GL pasture

The importance of P in the soil solution is reflected in the almost equal amounts of P and P extracted in the resin H_2O step In extracts of temperate soils Bic P is considered to contain mainly labile actively cycling P compounds while NaOH P was interpreted as moderately labile P compounds which reflect the slower long term transformations of soil P occurring during soil formation or prolonged cultivation In the present study labile Bic P was not affected by the conversion of native savanna into improved pastures while NaOH P was increased under the 14 year old GL pasture but not the GO pasture Consequently these results support a revised interpretation of these two fractions for tropical soils Bic P appears to be at a constant level regardless of the cropping history in some tropical soils while the NaOH P fraction reflects the overall changes in soil organic matter and P levels when the soil is stressed by cultivation and net P export This fraction may therefore represent a relatively active reservoir (source or sink) of P under tropical conditions

The observed increase in extractable soil P in GL was probably not due to inert plant material since the legume *Pueraria phaseoloides* is known to decompose at similar rates as the grass *Brachiaria decumbens* Given the increase in labile P fractions (Resin P_i Bic P Table 11) especially in the GL pasture P in plant residues and animal excreta seems to be recycled efficiently This is supported by the observation of higher acid phosphatase activity in improved pastures than in native savanna (181 ± 8 213 ± 14 239 ± 17 mg *p* nitrophenol kg^{-1} h^{-1} for SA GO and GL respectively) Phosphatase activity was at a high level for all treatments thus showing the significance of organic P in the soil P dynamics of improved pastures and native savanna

All extractable inorganic fractions were increased in the GL pasture but not the GO pasture (Table 11) The modifications observed in the GL pasture in labile fractions indicate an improvement in P availability which is also reflected in the results of the Bray II P soil test values (Table 11) Although their content is still very low the increase in labile P fractions is surprising given the low P inputs made by fertilizers (Table 12) and the medium to strong P sorption capacity of the soil

In all treatments differences in P fractions were largely in absolute values rather than relative terms This suggests that the preliminary partitioning of applied P among soil P fractions was not greatly influenced by improved pasture species either in GO or in GL systems Significantly the observed absolute increases in fraction sizes including fractions considered as readily available occurred almost entirely in the GL pasture

Table 11 Inorganic P fractions in the 0 10 cm soil layer in native savanna and improved pastures

	P fraction													
	Resin-P	H_2O-P	Bic P	Bic P	NaOH-P	NaOH-P	HCl_{hc} P	HCl P	HCl_{hc} P	Resid P_i	SumPT‡	Extr P_o§	PT¶	Bray II
	mg P kg⁻¹													
Mean SA	3 5 b	2 7 b	3 3 b	9 6	23 1 b	43 1 b	1 3	54 1 b	8 3	50 9 ab	200 b	63 8 b	185 b	1 3 b
SE	0 2	0 1	0 1	0 7	0 7	1 8	0 1	1 6	1 9	1 4	2	2 6	3	0 1
Sum %	1 7	1 4	1 7	4 8	11 6	21 6	0 6	27 1	4 2	25 4	100	31 9	92 3	
Mean GO	4 0 b	4 3 a	3 4 b	9 9	22 8 b	41 4 b	1 8	60 6 b	12 7	49 9 b	211 b	68 4 ab	193 b	1 4 b
SE	0 1	0 5	0 1	0 6	0 8	2 1	0 3	3 1	2 6	1 1	8	3 6	6	0 2
Sum %	1 9	2 1	1 6	4 7	10 8	19 6	0 9	28 8	6 0	23 6	100	32 3	91 5	
Mean GL	5 2 a	3 5 ab	4 6 a	9 6	31 1 a	51 9 a	1 5	68 6 a	12 1	54 9 a	240 a	77 1 a	227 a	2 2 a
SE	0 4	0 3	0 2	0 5	1 2	3 1	0 1	1 5	2 5	0 9	6	3 8	5	0 3
Sum %	2 2	1 5	1 9	4 0	13 0	21 7	0 6	28 6	5 0	22 9	100	31 2	93 9	
F test#	***		***	NS	***	**	NS	***	NS		***		***	**

†Mean and SE for 8 (GO and SA) and 7 (GL) samples per treatment Means followed by the same letter are not significantly different (P=0 05) by Tukey s multiple range test
‡Sum of all fractions
§Sum of extracted organic P fractions
¶Total P determined by perchloric acid digest

Table 12 Estimated P budget over 15 years (1978 1993) in native savanna and improved pastures and comparison with measured total P (PT) increases due to fertilization

Treatment	Estimated P budget			Measured PT difference †	Balance unaccounted for
	Input	Export ‡	Balance		
			kg P ha⁻¹		
SA		2 1	2 1		
GO	103	24	+79	10 4	70 7
GL	106	36	+70	54 6	17 5

† Difference in PT content (from table 3) between improved pastures and native savanna
‡ P export of 8 g P kg^{-1} of live weight gain (LWG) LWGs of 15 20 200 and 300 kg ha^{-1} yr^{-1} in SA GO and GL respectively

P budgets in native savanna and improved pastures

P budgets were estimated to determine the relation between P input in improved pastures and P output via beef cattle and to better understand the modifications in the size of P fractions or total P that occurred especially in the GL pasture P budgets were calculated by subtracting the P removed from the system by animals from the P applied in mineral fertilizer (Table 12) Positive P budgets were obtained for both improved pastures while a small negative budget was found for the unfertilized SA (Table 12) Clearly differences in PT as well as available P fractions between the GO and the GL pasture were not due to differences in P budgets

The calculated differences in the P budget are 81 kg P ha^{-1} between GO and SA and 72 kg P ha^{-1} between GL and SA (column 4 table 12) Assuming that all (non exported) applied P remained in the 0 10 cm surface soil layer and using a bulk density of 1 3 g cm^{-3} the measured PT differences (column 5 table 12) are smaller than the values estimated from the budget for the GO as well as for the GL treatment Especially for GO the discrepancy (column 6 table 12) clearly exceeds differences that might be explained by analytical errors One possible explanation for the observed discrepancies is that the P budgets were much less than estimated for both improved pasture types However overestimation of the P budget could only occur by underestimation of P exported in animal live weight gain (LWG) and it is unlikely that the error would be so large Moreover P exported would be expected to be similar for both systems or perhaps even greater from GL pastures given the higher P content in legumes than grasses

The alternative explanation is that P moved out of the surface soil into the soil profile and that there was a larger net movement of P out of the top soil layer in the GO pasture compared to the GL pasture It is very improbable that any significant movement of inorganic P would have occurred through leaching given the substantial sorption capacity of this soil However losses of soluble organic P as well as of particulate P may occur considering the high rainfall intensity the high P contents in the water of the resin extraction step (Table 11) and the fine texture of the soil

Although positive P budgets and increases in most P fractions were observed for both improved pastures the comparison of PT and the estimated P budget indicates P losses from the 0 10 cm layer especially in the GO pasture Consequently the integrated consideration of P fractions PT and P budget shows that the GO pasture is less resource conserving than GL

C/N and C/P ratios of different organic P fractions

Differences in the composition of soil organic matter extracted in the different steps or remaining in the soil residue are illustrated by their C/N and C/P ratios (Table 13) Since pasture type did not significantly affect these ratios only mean values for each extract are presented In general the C/N/P ratios (Table 13) especially C/P were high when compared to values known from the literature which are mainly based on studies on temperate soils C/N ratios varied more between extractants than C/P

Table 13 C/N C/P and N/P ratios in different extracts of the sequential fractionation procedure as well as C/N/P for N = 10 Geometric means over all field treatments

	H_2O	Bic	NaOH	HCl_h	Extr†	Resid	Total‡
C/N	16 0	6 5	16	9 0	11 5	28	14
C/P	229	197	192	354	212	176	345
N/P	14	33	12 4	39	18 4	6 3	20
C/N/P	160/10/0 71	65/10/0 33	160/10/0 80	90/10/0 26	115/10/0 54	280/10/1 6	137/10/0 51

† Ratio between sum of extracted C N and P respectively
‡ Ratio between total C total N and the sum of extracted organic P

The C/P ratio in soil and plant residues added to soil has been used to predict net immobilization and mineralization *in soil with P mineralization* occurring at ratios of 200 or less and P immobilization when ratios are 300 or more Consequently fertilizer P added to any treatment of the present study would be immobilized in organic matter However the increase in available inorganic P fractions (Table 11) especially in the GL pasture occurring at the same time as an increase in total C and N (data not shown) suggests an inconsistency in the principle based on C/P index Plant litter of improved grass and legume species has a C/P ratio *ranging from ca* 400 to 2700 Consequently wider C/P ratios in these soils are likely an indicator of recent organic material and therefore an indicator of P with a high availability when P is mineralized concomitantly to C and N driven by the need for energy The high phosphatase activity in all treatments included indicates the importance of biochemical or biological processes in P mineralization

Based on the high C/P ratios observed in the present study not only in stable fractions but also in labile P fractions a re evaluation of the critical C/P concept is required especially when used as a parameter for modelling P turnover eg in the Century model (see contribution of Gijsman et al in this annual report)

Factors enhancing P availability in GL pastures

For many of the variables included to investigate P transformations GL shows a more distinct separation from SA than GO does Increases in P_i fractions considered as readily plant available show that P added to the soil via fertilizer plant litter and animal excreta cycles more efficiently in the GL pasture Explanations for the fact that only small P inputs via fertilizers enhanced P cycling in the GL more than in the GO pasture may be found in the differences in soil floral and faunal activity as well as by the intervention of plants in P cycling A recent diploma thesis which studied these pastures showed that macrofaunal biomass in the GL treatment was twice that of the GO treatment which was double that of SA with earthworms being the dominant macrofaunal species P availability is apparently enhanced in casts of earthworms The greater importance of processes linked to biological activity are also indicated by the slightly higher phosphatase activity in GL than GO pastures Furthermore microbial P which is considered to be the second most active soil P pool after solution P was larger in the GL pasture compared with GO which in turn was slightly higher than SA (data not shown)

Root growth and characteristics may also affect P cycling efficiency In this respect legumes may be more efficient cyclers or at least promote more efficient cycling in mixed pastures than grasses Evidence of this may be seen in the comparatively higher cation concentrations (especially Ca) in the surface soil of the GL pasture (data not shown)

In summary therefore initial low P inputs through fertilizers (Table 12) and N input by legumes have enhanced nutrient cycling Excreta from grazing livestock make a more important contribution to the nutrient enrichment in the top most soil layer of improved pastures than in the SA as a result of increased plant production stocking rate and higher nutrient contents especially in legumes Together with the plant litter excreta lead to improved nutrient conditions for soil flora and fauna As a result of interactions between chemical and biological soil properties P availability is increased

Nutrient cycling through the microbial biomass *A Gijsman A Oberson (U Saskatchewan) D Friesen (IFDC) J Sanz R Thomas (TL)*

Introduction

Soil microbial biomass has been shown to be a sensitive indicator of changes in soil organic matter (SOM) quality and quantity It responds relatively rapidly *i e* compared to total SOM to changes in organic inputs to the soil or in soil management and differences in microbial biomass can be detected before they can be measured in total SOM Besides being useful as an indicator of the organic matter status of a soil the importance of microbial biomass is found in its central role in nutrient cycling in a soil Strong correlations have been found between the amount of nutrients held in the microbial biomass and levels of mineralizable nutrients in the soil indicating that nutrient cycling in a soil is tightly linked to the turnover of microbial biomass The objective of the present study was to determine which changes in microbial biomass occur when native savanna whose organic matter content may be expected to be at equilibrium level is opened up and brought under cultivation Microbial C N and P contents and C and N mineralization rates were determined in soil from 5 year monocrop rice and various forms of rice pasture rotation

Materials and Methods

Soil samples were taken from the 0 10 cm soil layer of a five year old rice pasture rotational experiment (Table 14) on a clay loam Oxisol at Matazul farm in the eastern Llanos of Colombia Microbial biomass C N and P content (fumigation extraction method) and of C and N mineralization rate (10 day incubation) were measured

Table 14 Crop rotation schedule of the experiments

Code	until 1988	1989	1990 1992	1993
R GL	native savanna	rice	grass legume	grass legume
R G	native savanna	rice	grass	grass
R GL R	native savanna	rice	grass legume	rice
R G R	native savanna	rice	grass	rice
CR	native savanna	rice	rice	rice
SAV	native savanna	native savanna	native savanna	native savanna

Results and Discussion

Microbial biomass nutrient contents Microbial biomass C did not vary much among treatments all treatment averages being within a 13% deviation from the overall average (Table 15) No differences were found between pasture or cropped plots Microbial biomass N was considerably lower for the CR treatment than for the other treatments Consequently the microbial biomass C/N ratio was more than one and a half times as wide under continuous rice as under any other rotation treatment and the contribution of microbial N to total organic N content (N_m /N_g) was also low This probably reflects the input of low N rice residues at harvest Left over nitrogen from fertilization obviously did not compensate for the material s high C/N ratio It may also be that fungi having a wider C/N ratio than bacteria made up a larger fraction of the microbial population possibly because the vertical distribution of freshly added residues in the CR treatment was different as most crop residues at harvest were deposited on top of the soil Fungi are relatively more important for the decomposition of surface litter

The data on microbial biomass P showed a distinction between the continuous rice and native savanna on the one hand and the rice pasture and rice pasture rice plots on the other the former group showing lower biomass P values Within each of these two groups differences were non significant Biomass C/P ratio s showed the same two groups however with the exception of the R G treatment in which the C/P ratio was relatively high The microbial C/P ratios are at the very high end of the range commonly found suggesting that the microbial population may have adapted itself to the low P conditions of this soil Despite these wide C/P ratios the contribution of microbial biomass P to total SOM P agrees well with values commonly found in temperate soils with a much higher P fertility The significance of this consists in it that P absorbed in microbial cells becomes part of a pool which turns over dynamically whereas without this microbial uptake it might have become unavailable to the plant due to the strong P sorption capacity of these soils The microbes thus compete successfully for inorganic P and may contribute significantly to P cycling

C and N mineralization and microbial activity

The carbon mineralization rate during the 11 day incubation period was highest in the R GL pasture followed by the R G pasture (Table 16) The cropped plots especially the continuous rice and the native savanna showed a lower C mineralization rate than the pasture plots The same picture was found for the fraction of organic C that was mineralized per day (C_m /C_{g}) In most samples net nitrogen immobilization occurred as amounts of extractable N after incubation were lower than before incubation Only in the savanna treatment net N mineralization was positive on average (Table 16) but this value was strongly biased by one positive outlier Rejecting this one value would bring the savanna average down to 0 27 μg g^{1} d^{1} which is within the range of the other treatments values Obviously the incubation period had not been long enough to result in a net N mineralization Carbon nitrogen ratios of the decomposed organic matter consequently could not be calculated

Table 15 Microbial C N and P contents and their contribution to total organic C N and P contents in soil from various rice pasture rotations and native savanna[1]

Treatment	C	N	P	C N	C P	C_{mic}/C_{org}	N_{mic}/N_{or}	P_{mic}/P_{or}
		(μg g)					(%)	
R GL	486 8	66 3	13 0	7 6	36 5	2 6	5 2	16 0
R G	520 1	63 2	11 5	8 3	45 5	2 4	4 7	11 9
R GL R	441 1	52 9	13 0	8 5	34 1	2 2	3 7	12 1
R G R	543 7	66 4	13 6	8 2	39 2	2 4	4 6	14 1
CR	434 1	34 3	9 6	13 0	48 0	2 2	2 5	6 8
SAV	473 4	53 1	9 6	9 3	49 6	2 6	4 4	11 7

[1] The statistical significance of the results is not indicated since this part of the analysis has not been done yet For treatment codes see Table 14
C_{mic}/C N_m /N P_m /P_{rg} = contribution of microbial C N and P to organic C N and P

Table 16 Mineralization of C and N during an 11 day incubation of soil from various rice pasture rotations and native savanna[1]

Treatment	C	N	C_{min}/C_{rg}	qCO [5]
	– (μg g d)		(% d)	(μg CO2 C mg biomass C hr)
R GL	6 74	0 65	0 033	0 58
R G	5 81	0 55	0 026	0 47
R GL R	4 65	0 25	0 023	0 44
R G R	4 80	0 53	0 024	0 37
CR	3 36	0 54	0 017	0 32
SAV	4 51	0 02	0 023	0 40

[1] The statistical significance of the results is not indicated since this part of the analysis has not been done yet For treatment codes see Table 14
C_{mi} /C_{or} = fraction of organic carbon mineralized per day
[5] qCO = metabolic quotient

The C mineralization rate per unit biomass C (metabolic quotient qCO_2) was highest in the R GL treatment and lowest in the CR treatment The two treatments involving a legume in the rotation (R GL and R GL R) had a higher qCO_2 than the comparable treatments without a legume (R G and R G R) A higher qCO_2 indicates that either a greater fraction of the total microbial population was active (due to a greater substrate availability) or the energy use efficiency of these organisms was lower The latter is not likely here since the treatment whose plant residues were most N rich and thus could be decomposed with a relatively high metabolic efficiency (R GL) yet had the highest qCO_2 It is therefore assumed that a greater fraction of the microbes was active under pasture than under cropping probably because of differences in organic matter input Whereas in cropping systems organic matter input to the soil largely occurs as an annually or semi annually repeated pulse in pastures there is a *continuous input from dead roots grazing* losses faeces and urine Moreover the amount of plant residues returned to the soil is usually lower under cropping since part of the plant production is harvested and thus removed from the field This makes it probable that the microbial population under pasture stays in a more active form

Nutrient cycling through microbial biomass turnover

Assuming a microbial turnover time in the range of 0 5 to 1 0 year the amount of nutrients cycling through the microbial biomass was calculated Table 17 shows that the microbial biomass can contribute considerably to plant nutrient supply particularly when taking into account that the calculations only refer to the 0 10 cm soil layer Moreover the contribution of microbial metabolites to nutrient cycling should also be added to these numbers It is also clear however that this nutrient cycling pathway can supply much less nutrients (especially N) in the rice monocrop than in the other treatments This is related to the fact that *in the monocrop a smaller fraction of the organically* bound nutrients is in the microbial biomass (Table 15) suggesting there is less young organic matter The reduced residue input to the soil due to removal of grain and straw from the field and the higher organic matter decomposition rate due to frequent soil disturbance by tillage are at the root of this

Table 17 Nutrient flux through microbial biomass (kg ha yr) at two turnover times in soil from various rice pasture rotat ons and native savanna[1]

	τ=0 5		τ=1 0	
Treatment	N	P	N	P
R GL	165 8	32 6	82 9	16 3
R G	157 9	28 6	79 0	14 3
R GL R	132 1	32 4	66 1	16 2
R G R	166 0	33 9	83 0	17 0
CR	85 6	23 9	42 8	11 9
SAV	132 7	24 1	66 4	12 1

[1] The statistical s gnificance of the results is not indicated since this part of the analysis has not been done yet
For treatment codes see Table 14
τ = microbial turnover time (yr)

In strongly P sorbing soils such as the Oxisol of the present study very little inorganic P (P) may be readily exchangeable and the availability of P may depend more on the turnover of easily decomposable soil organic matter than on the release of adsorbed inorganic P The immobilization of P by microbes and its gradual release by microbial turnover provide a mechanism by which P is protected from physic chemical adsorption reactions In the present experiment more P was held in microbial biomass than was resin exchangeable (except for the CR treatment which was annually fertilized with P Oberson *et al* unpublished data) The size of the P flux through the microbial biomass (between 12 and 34 kg ha^{-1} yr^{-1}) indicates that this could be a major pathway of P cycling in these low P soils

Evaluation of some Physical Properties of an Oxisol after Conversion of Native Savanna into Legume based or Pure Grass Pastures *A J Gijsman (U Saskatchewan) and R J Thomas (TL)*

Introduction

Little information is available on short or long term development of the physical conditions of soil under pastures established in previously native savanna Instead most work in this field has been done with pastures established after clearing a tropical forest where a considerable change in soil physical characteristics may be expected given the drastic nature of the land conversion and the methods used for the clearing Earlier it was shown that there was no difference in soil aggregate distribution between grass only and grass legume pastures established in previously native savanna but that the aggregates were somewhat more stable in the presence of a legume Here data are reported on a number of other soil physical characteristics of these pastures

Materials and Methods

Soil samples were taken from two adjacently situated experiments on grass only and grass legume pastures on a clay loam Oxisol in Carimagua (Table 18) A native savanna control was also included Plots were 1 ha each but in experiment 2 they were divided into two halves for alternate grazing only one of the two halves was used for sampling Experiments 2 and 3 were replicated but for experiment 1 the replicate plot was no longer available However because the plots in this experiment were not divided into two as in the other pasture experiment a pseudo replicate was created here by dividing the plots into two halves for the sampling

The following soil physical parameters were determined

Water retention characteristics
Unsaturated hydraulic conductivity as calculated from the water retention characteristics using a curve fitting computer program for water retention curves
Apparent bulk density
Total porosity and pore size distribution as calculated from the water retention curve
Penetrometer resistance
Water infiltration rate with a double ring infiltration system

Table 18 Treatment schedule

Treatment	Code
B decumbens	Bd
B decumbens + *Pueraria phaseoloides*	Bd/Pp
B humidicola + 2 an /ha[A]	Bh+2
B humidicola + *Arachis pintoi* + 2 an /ha	Bh/Ap+2
B humidicola + 4 an /ha	Bh+4
B humidicola + *Arachis pintoi* + 4 an /ha	Bh/Ap+4
Savanna	Sav

an /ha = animals per hectare

Results

Apparent Soil Bulk Density and Penetrometer Resistance

The apparent soil bulk density varied from 1 23 to 1 30 g cm^{3} (Table 19) with no differences between treatments

The penetrometer resistance increased steeply with depth in all treatments down to a depth of about 40 to 50 cm (Fig 16) The data show a higher resistance in the topsoil of the savanna compared with the pastures the opposite being found in the subsoil (statistical analysis of this difference was not possible) Inclusion of a legume in the pasture did not affect the penetrometer resistance in the *B decumbens +/ P phaseoloides* experiment but in the *B humidicola +/ A pintoi* experiment the penetrometer resistance was slightly higher in the grass legume treatments than in the grass only treatments (P<0 001) Increasing the stocking rate also resulted in a slightly higher penetrometer resistance (P<0 001) These *differences were independent of depth*

Water Retention The volumetric water content at saturation was about the same for all treatments in both soil layers (Fig 17) For the 0 5 cm soil layer the decline in water content with increasing *pF* occurred more rapidly in the native savanna than in the pasture treatments with a relatively low stocking rate (*i e* the *B decumbens +/ P phaseoloides* experiment and the low stocking rate treatments of the *B humidicola +/ A pintoi* experiment) The high stocking rate treatments of the latter experiment had a similar *pF* curve as the native savanna showing a more rapid decline in volumetric water content (Θ) with increasing *pF* than the low stocking rate treatments (not significant although P<0 10) In the 6 11 cm soil layer the *pF* curves of the high and low stocking rate treatments in experiment 2 also stood apart clearly (significant for *pF*≥2) The *pF* curves did not differ between grass only and grass legume treatments except for the 6 11 cm layer of experiment 1 This latter difference however could be attributed to one sample with a relatively high water content in the high *pF* range and was not significant

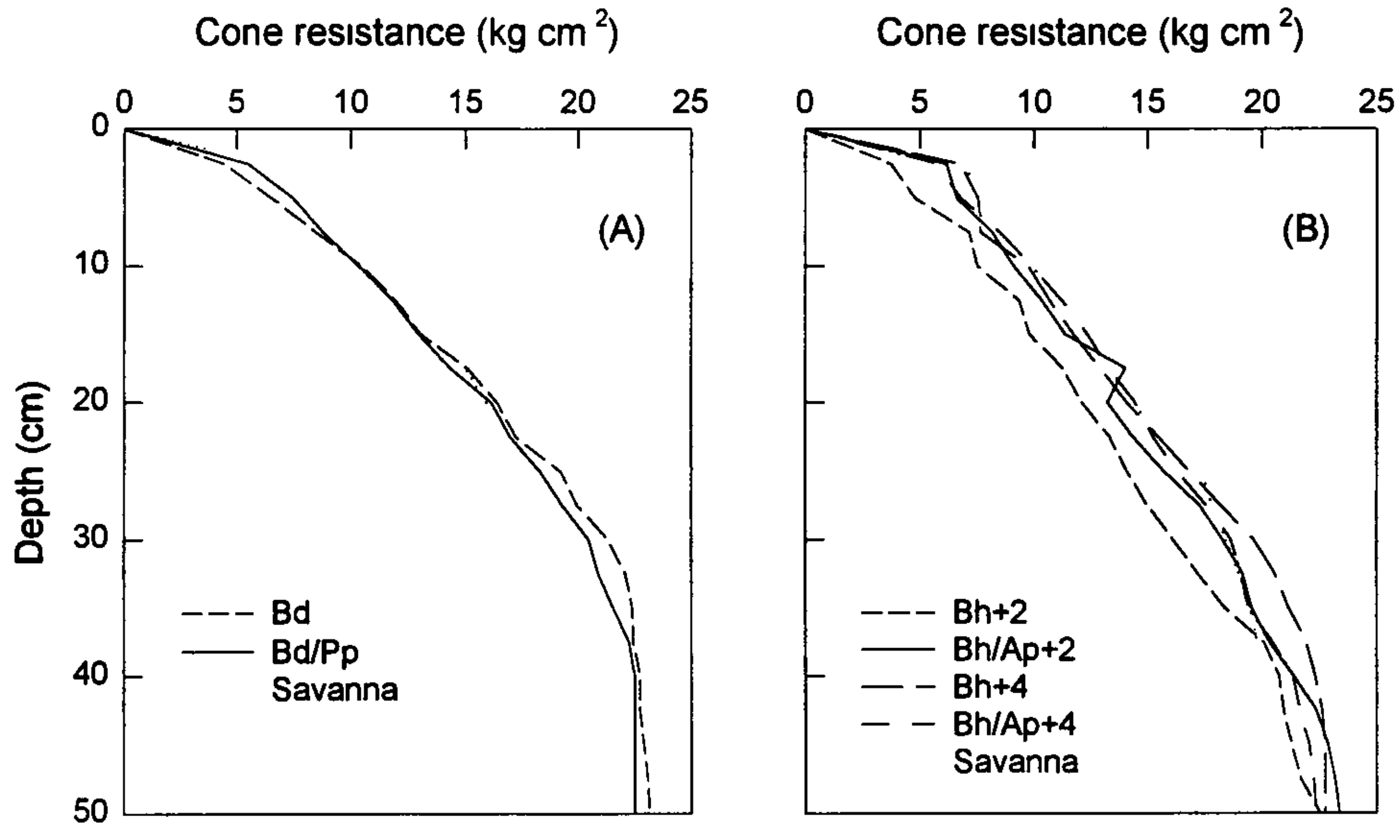


Figure 16 Cone resistance of an Oxisol under improved pasture or native savanna (A) = B decumbens +/ P phaseoloides, (B) = B humidicola +/ A pintoi For an explanation of the treatment codes see Table 18

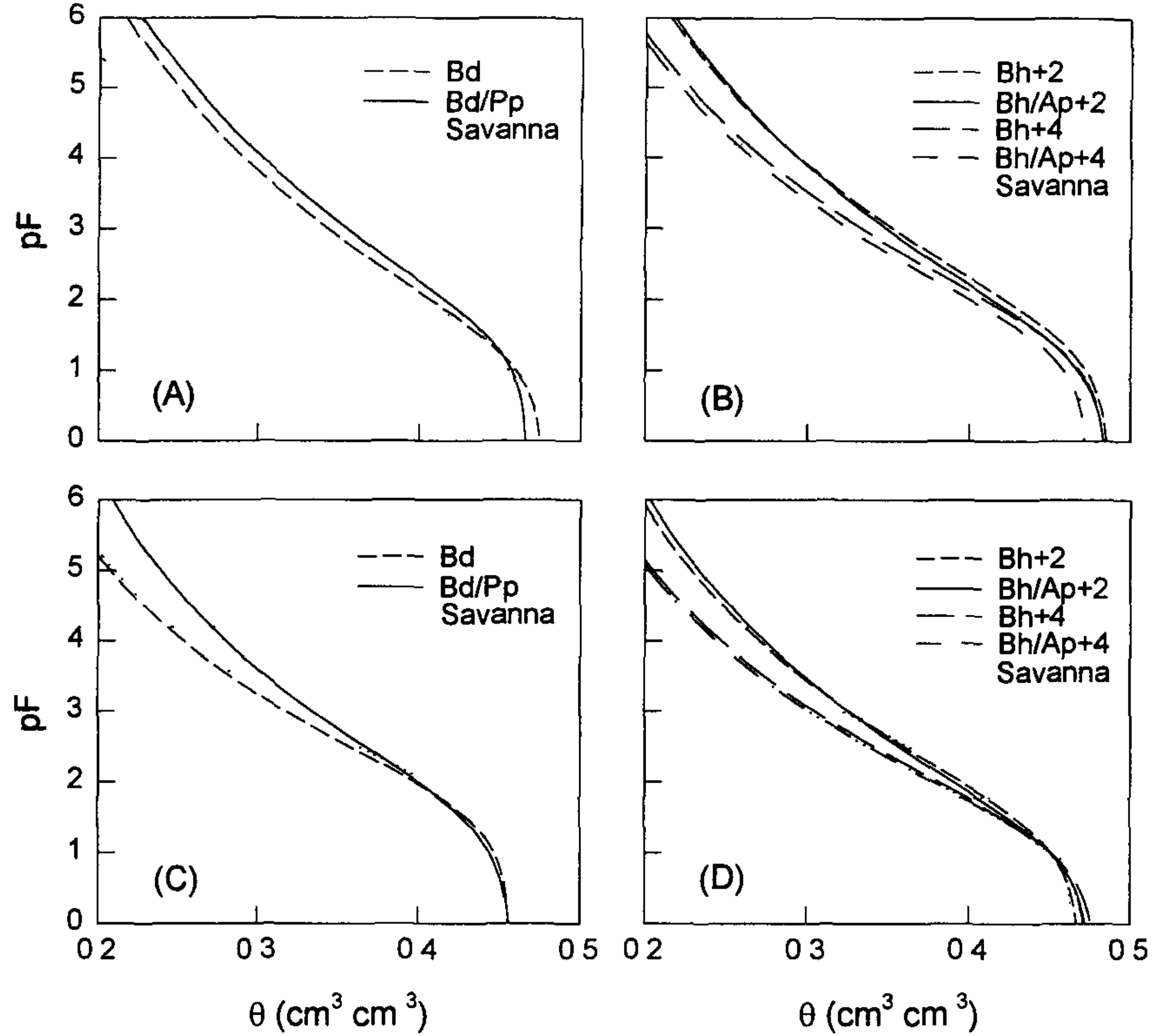


Figure 17 Water retention curves of two soil layers of an Oxisol under improved pasture or native savanna Dotted horizontal lines indicate the range of plant available water (see text) (A) (C) = B decumbens +/ P phaseoloides layer 0 5 cm and 6 11 cm respectively (B) (D) = B humidicola +/ A pintoi layer 0 5 cm and 6 11 cm respectively For an explanation of the treatment codes see Table 18

The plant available water content of the soil was calculated as the difference between the upper drained limit of the water content (field capacity here taken at a pressure of 60 cm) and the water content at wilting point (generally taken at a pressure of 15 bars) This yields a plant available water content between 13 4 and 17 5% of the soil volume (data not shown) with the lowest values in the treatments with a relatively low stocking rate (both experiments) There were no differences between treatments in either of the soil layers

Total Porosity and Pore Size Distribution Since water saturated soil usually contains entrapped or dissolved air (unless saturation occurred under vacuum) the saturated water content O does not provide an exact measure of total porosity This difference however is only in the order of 5 to 10% so no correction is made here Table 19 shows that for all treatments and soil layers total porosity ranged from 0 46 to 0 49

Table 19 Various soil physical parameters of two layers of an Oxisol under improved pasture or native savanna

Treatment[A]	Bulk density (g cm 3)	Total porosity (cm cm 3)	Pore size distribution (cm3 cm 3)			
			<0 1μm	0 1 5μm	5 30μm	>30μm
			Layer 0 5 cm			
Bd	1 30	476	232	103	059	082
Bd/Pp	1 29	466	234	109	059	063
Bh+2	1 27	487	220	119	068	080
Bh/Ap+2	1 27	485	221	112	064	088
Bh+4	1 28	485	192	125	075	093
Bh/Ap+4	1 28	473	186	122	074	090
Sav	1 30	483	177	120	074	112
			Layer 6 11 cm			
Bd	1 30	456	186	126	075	070
Bd/Pp	1 30	458	208	113	065	072
Bh+2	1 24	469	194	115	069	092
Bh/Ap+2	1 24	475	199	107	064	104
Bh+4	1 24	479	164	119	076	121
Bh/Ap+4	1 23	474	161	118	077	118
Sav	1 29	465	174	135	081	075

[A]See Table 18 for explanation of treatment codes

The pore size distribution (Table 19) reflects the differences observed in the *pF* curves setting apart the low from the high stocking rate treatments the latter having a relatively small volume of small pore space and large volume of large pore space These differences were significant for the pores <0 1 μm and >30 μm in the soil layer 0 5 cm of the *B humidicola +/ A pintoi* experiment No legume effect was found

Calculated Unsaturated Hydraulic Conductivity The calculated unsaturated hydraulic conductivity (*K*) of the pasture soils (Fig 18) was generally lower than that of the native savanna soil the difference being most pronounced for the pasture treatments with a relatively low stocking rate (*i e* the *B decumbens +/ P phaseoloides* experiment and the low stocking rate treatments of the *B humidicola +/ A pintoi* experiment) An exception was the 6 11 cm soil layer of the *B decumbens +/ P phaseoloides* treatment which was largely due to one outlier sample with a relatively low *K* at low values of O

No consistent legume or stocking rate effects were found although for the 6 11 cm layer of the *B humidicola +/ A pintoi* experiment *K* was significantly lower for the +legume treatments than for the legume treatments at *h* values less negative than 150 kPa

Water Infiltration The measured cumulative water infiltration and the fitted curves are shown in Fig 19 The fit between curve and data was tight with R^2s of individual infiltration measurements varying from 0 988 to 1 000

A difference in water infiltration rate was observed between the grass only and the grass legume pastures the latter showing a more rapid water infiltration (significant at $P<0$ 005 for the *B humidicola +/ A pintoi* experiment) This could be attributed to a higher terminal water infiltration rate (*A*) and except for the *B humidicola +/ A pintoi* treatment at low stocking rate also a higher sorptivity (*S*) in the grass legume pastures

A slight (non significant) decline in water infiltration rate with increasing stocking rate was observed in the *B humidicola +/ A pintoi* experiment This was due to a decline in terminal infiltration rate the results on sorptivity being variable

Water infiltration in native savanna soil was slower than in the grass legume pastures It was also slower than the grass only pasture of the *B decumbens +/ P phaseoloides* experiment but faster than or equal to the infiltration in the grass only pastures of the *B humidicola +/ A pintoi* experiment

Discussion

The inclusion of a legume in the pastures did not have much effect on the soil s bulk density total porosity pore size distribution water retention characteristics or calculated unsaturated hydraulic conductivity (the latter two being a result of the porosity parameters) Although the legume effect on penetrometer resistance was significant it was not big enough to be of much practical importance In striking contrast is the increase in the water infiltration rate in grass legume compared with grass only pastures The two grass only treatments in the *B humidicola +/ A pintoi* experiment also showed a reduced water infiltration rate compared with the native savanna The apparent lack of correspondence between the data on water infiltration rate and porosity can be explained from Poiseuille s Law which relates the rate of flow through a porous medium to the 4 h power of the capillary radius Thus small changes in pore diameter can have a profound impact on the hydraulic conductivity of a soil while hardly affecting total porosity Moreover small pores can conduct large volumes of water as long as they are continuous but they do not contribute much to total porosity Differences of scale in the methods used may conceal shifts in porosity since larger pores or soil cracks have a low chance of being sampled in the small sampling cylinders but are more likely to be included in the much larger infiltration cylinders

The legume effect on the soil physical condition may be related to the strong increase in earthworm biomass in the presence of a legume as earthworms create vertical channels in the soil thus stimulating water infiltration Another explanation may be found in the fact that many legumes especially *A pintoi* have a relatively coarse root system compared with that of grasses The channels left behind in the soil by old legume roots may contribute to creating relatively large pores throughout the profile providing conduits for by pass flow of water

The more rapid water release with increasing pF in the high stocking rate treatments of the *B humidicola* +/ *A pintoi* experiment than in the low stocking rate treatments indicates a larger fraction of relatively large soil pores in the former (Table 19) Total porosity was not affected by stocking rate This may be related to a higher root turnover due to the more frequent and thorough defoliation resulting in a relatively large number of old root channels At higher stocking rates this effect may be counteracted by compaction effects However despite this increase in large pore fraction water infiltration rate had decreased in the high stocking rate treatments which may reflect the earlier mentioned differences of scale in the methods used

Conclusions

Although the physical condition of a soil after conversion of native savanna into pasture is likely not to change as dramatically as in case of conversion of primary forest into pasture the results presented here have implications for soil management The soils under improved pasture generally had a lower calculated unsaturated hydraulic conductivity than under native savanna at given value of O or formulated differently were wetter at a given value of *K* This implies that with a given amount of rain thus at a particular *K* under conditions of steady infiltration the pasture soils are more susceptible to being damaged by animal trampling or tillage On the other hand adding a legume to a pasture positively affects the soil physical condition The higher water infiltration rate under grass legume pastures may add to reducing the risk of soil loss by water erosion

A cautionary note about the use of the CENTURY soil organic matter model for ecosystems on tropical low P soils *A J Gijsman A Oberson H Tiessen (U Saskatchewan) and D K Friesen (IFDC)*

Introduction

One of the most widely used models on organic matter dynamics in a soil plant animal system is the CENTURY model Although developed for use in temperate ecosystems the model has now also been adopted for use in the tropics by the Tropical Soil Biology and Fertility (TSBF) Programme and the Slash and Burn Project However many tropical ecosystems are on strongly phosphorus sorbing soils where P and not N is the limiting nutrient This has important implications for the application of CENTURY Modelling of nutrient cycling requires a detailed knowledge about the size and transformations of the various organic and inorganic nutrient pools and the flows between them For carbon and nitrogen a large body of data is available on these topics but for phosphorus information is far more scanty and with a few exceptions is uniquely obtained from soils of the temperate zone which are not as strongly P sorbing as certain tropical soils Data on interactions between organic and inorganic P are rare

We ran the model for an acid low P Oxisol with native savanna vegetation in the eastern plains of Colombia Simulations of SOM content were inaccurate both in quantity and quality despite the fact that detailed soil P fractionation data were available to parameterize the model As we believe that this could be related to poor simulation of soil P dynamics by the model we analyze here the P submodel of CENTURY with special reference to its use for tropical low P soils

The P cycle and plant available P

Phosphorus exists in the soil in inorganic (P) and organic form (P) both of which are involved in the cycling of P among soil plants microorganisms and animals Figure 20 shows a conceptual P cycle with its components Whereas at least for the temperate zone the contribution of P_i from organic phosphorus mineralization to plant available P_i is considered of minor importance within a single growth cycle the need to look at P cycling (consequently including P) rather than available P pool size has been recognized for perennial plants and natural ecosystems Under tropical conditions P was shown to contribute significantly to crop P uptake and several studies indicate that organic P might play a major role in P fertility of tropical soils

Assessment of P_i and P by sequential extraction

The only approach which has given moderate success in the evaluation of short term available P and P is a sequential P fractionation method (Figure 21) It aims at quantifying labile (plant available) P Fe and Al associated P Ca associated P_i as well as labile and more stable forms of P using the following extracts resin 0 5*M* $NaHCO_3$ 0 1*M* NaOH 1*M* HCl and hot concentrated HCl Due to the reactivity of P with the soil mineral phase determination of a potentially mineralizable P pool analogous to the mineralizable N or S pools measured by incubation and leaching techniques is not feasible The nature of different extractable P pools is even less well defined than that of the P_i pools Their turnover and availability often depend on the mineralization of C during which P is released as a by product although soluble P will be rapidly mineralized by soil enzymes This complex situation means that there is presently no satisfactory method for measuring available P beyond the rather empirical sequential extraction combined with conceptual models and possibly separate organic matter studies

The structure of the P submodel of CENTURY

The P submodel of CENTURY shown in Figure 22 consists of an organic P and an inorganic P section (respectively the left and right parts of the figure) the two being linked when inorganic P enters the organic cycle via P uptake by roots or microbes or P adsorption onto organic matter

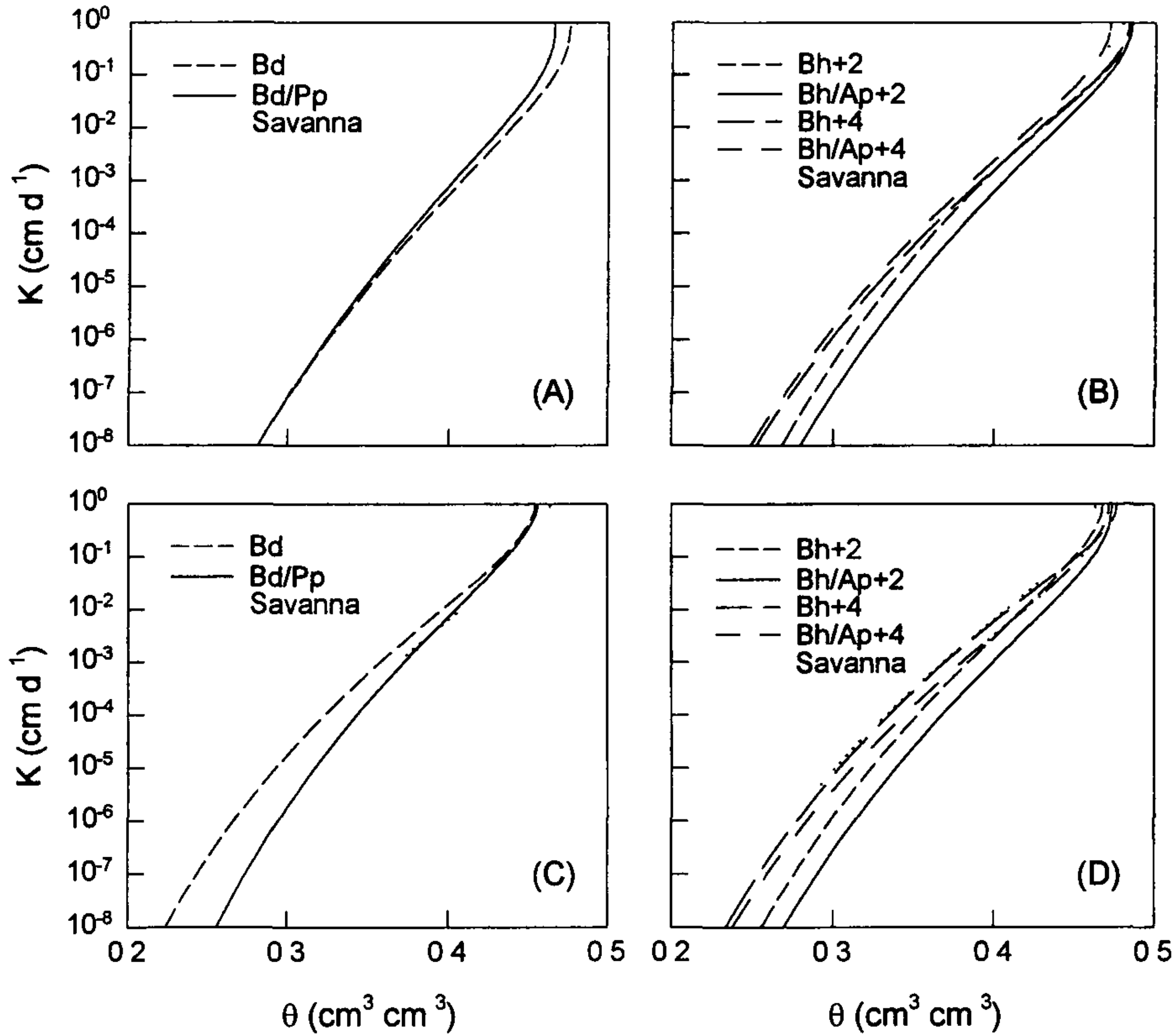


Figure 18 Calculated unsaturated hydraulic conductivity as a function of the volumetric water content (Θ) of two layers of an Oxisol under improved pasture or native savanna (A) (C) = B decumbens +/ P phaseoloides layer 0 5 cm and 6 11 cm respectively (B) (D) = B humidicola +/ A pintoi layer 0 5 cm and 6 11 cm respectively For an explanation of the treatment codes see Table 18

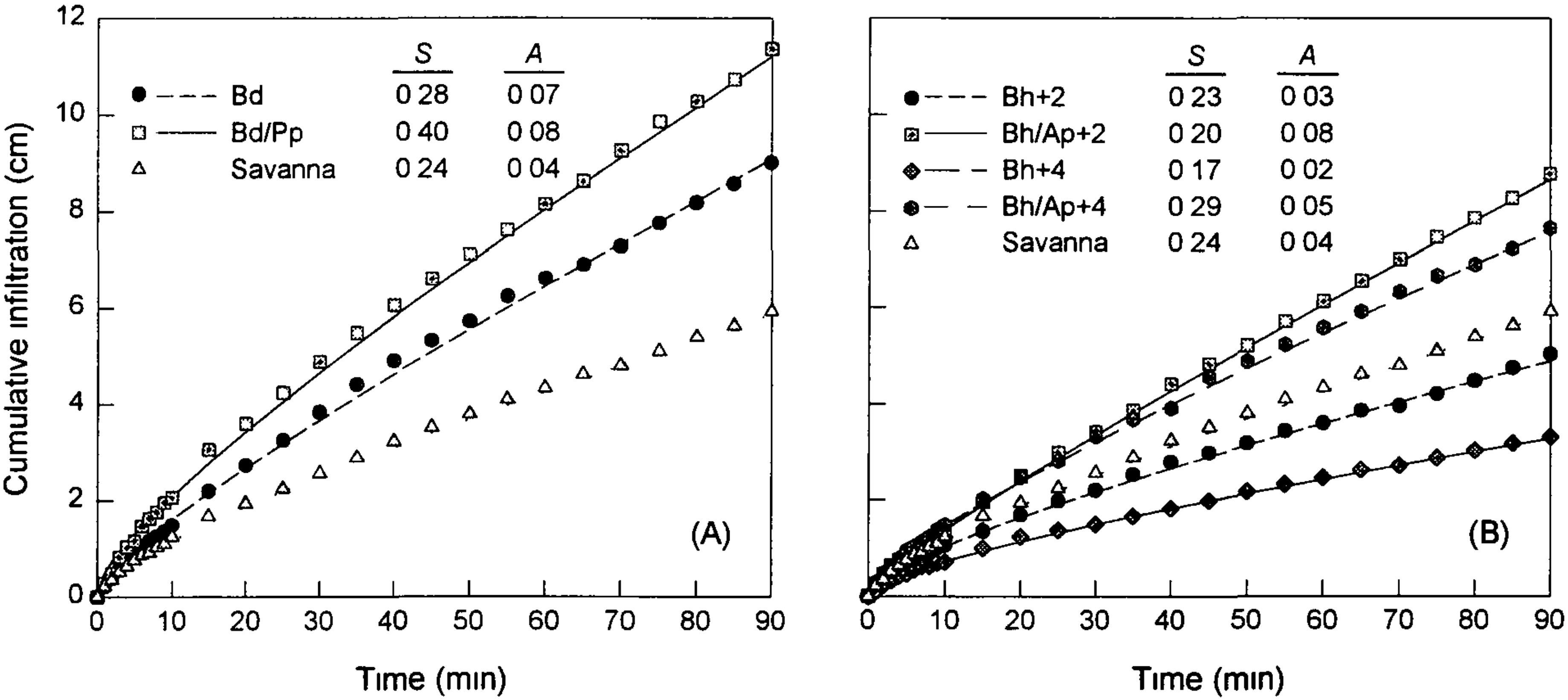


Figure 19 Cumulative water infiltration over a 90 minute period in an Oxisol under pasture or native savanna (A) = B decumbens +/ P phaseoloides (B) B humidicola +/ A pintoi For an explanation of the treatment codes see Table 18 S = sorptivity (cm min $^{1/2}$) A = terminal water infiltration rate (cm min ^{1})

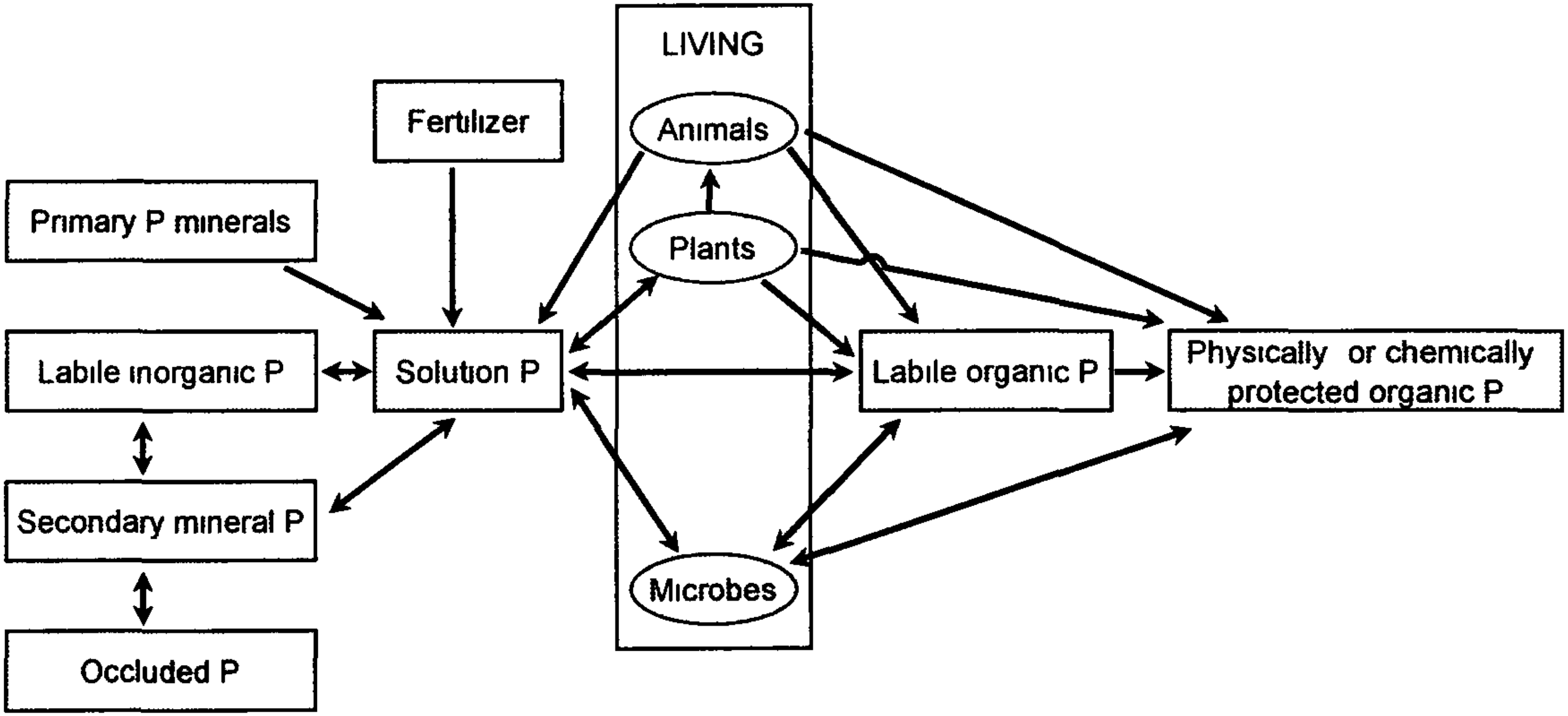


Figure 20 A conceptual model of the P cycle in an ecosystem

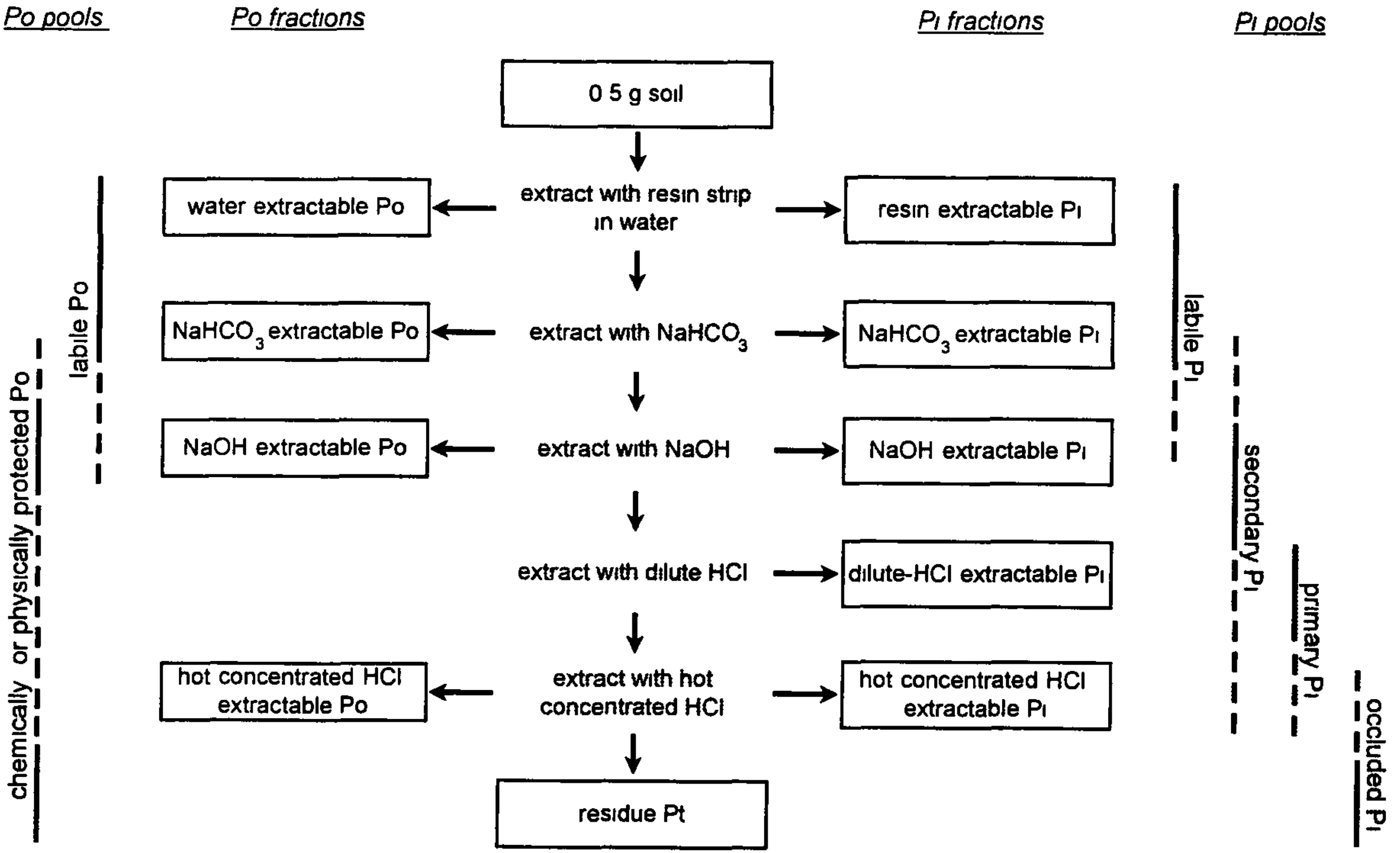


Figure 21 The P fractions obtained during a sequential P fractionation and an approximation of how to link P fractions to P pools

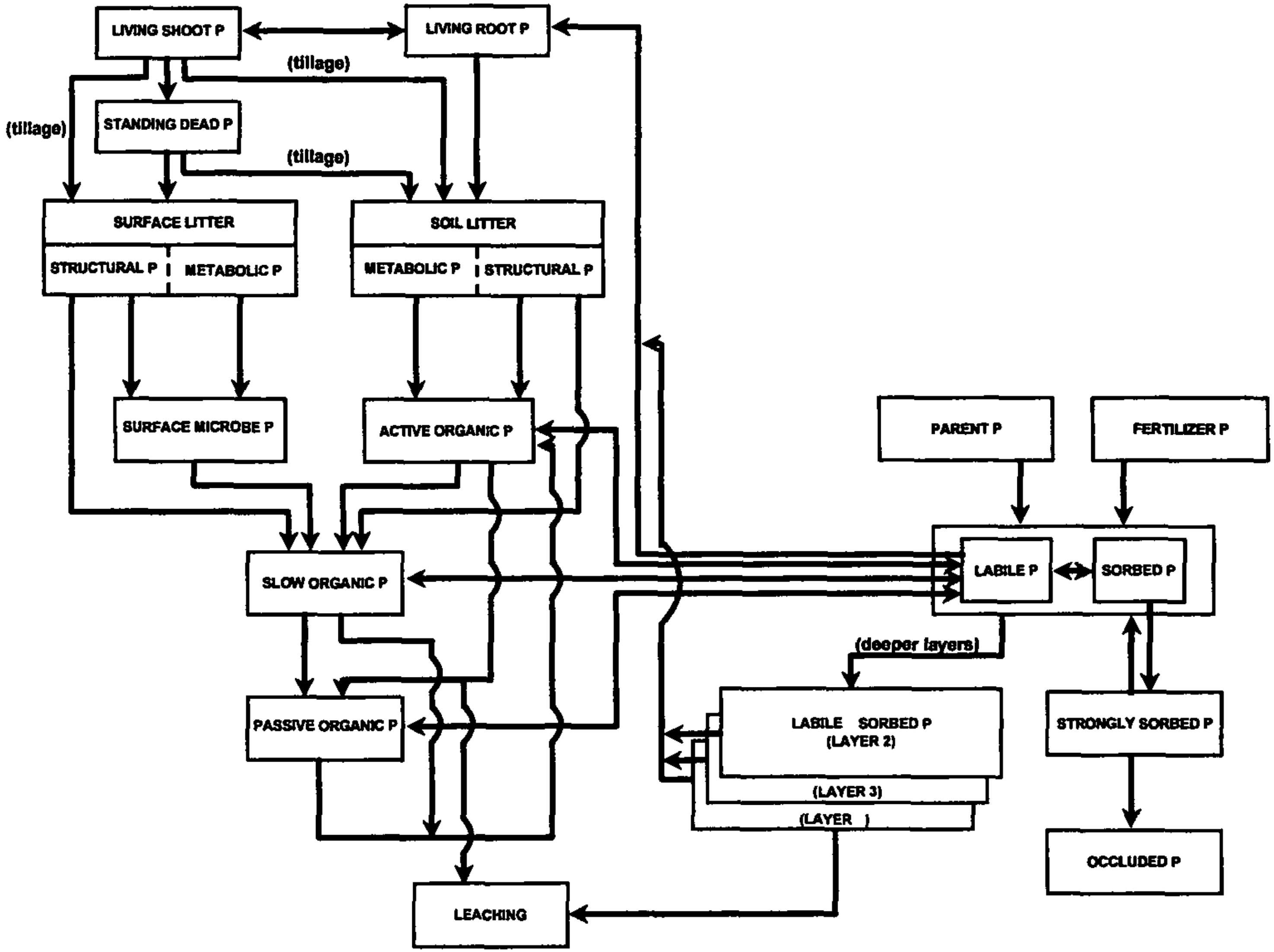


Figure 22 The structure of the P submodel of CENTURY

Limitations to the application of the P submodel

P_i pools vs P_i fractions The inorganic P section of the CENTURY model includes five P_i pools labile sorbed strongly sorbed occluded and parent P the size of which has to be estimated for a proper parameterization of the model It would be ideal if one could simply assign different P fractions from a sequential fractionation to different P pools However a pool is usually defined as a homogenous entity of substance characterized by identical kinetics of transport and transformation whereas an extractable P_i fraction is only characterized by its extractability with a certain extractant without this latter necessarily being an indication of having similar kinetics or even structural properties Phosphorus present in a certain extraction fraction therefore may originate from various P pools and consequently consist of P forms with different plant availability By comparing data from sequential P fractionations with experimental observations on P availability and transformations empirical relationships can be established correlating fractions with pools and estimating net transfers between them The P status of a soil can then be characterized relative to a conceptual model of P pools and their transformations For the dominant soil types of the temperate zone a substantial database exists on P fractionation in relation to P availability but for the low P soils commonly found in the tropics such a database is only beginning to build This makes it virtually impossible to parameterize this part of the model reliably even if sequential P fractionation data are available

Flows between P_i pools In the CENTURY model the flows between the P pools are formulated as first order reactions of the type

$$\textit{Flow} = \textit{rate constant} * \textit{pool size} * \textit{abiotic reduction factor} \qquad [1]$$

Whereas defining the P pools already poses considerable problems estimating the rate constants for the transfers between these pools is even more uncertain The difficulty is due to the numerous competing reactions inorganic and organic which are occurring both concurrently and consecutively in soil systems Reactions in which P moves from the solid phase or from organic pools to inorganic pools may be expected to follow different kinetic equations Enzyme mediated dephosphorylation reactions are likely to follow higher order kinetics than the first order processes assumed in the model Besides these limitations the greatest difficulty remains estimating kinetic parameters of individual processes in the complex milieu of the soil

The abiotic reduction factor (range 0 1) in equation [1] consists of a temperature and a moisture related component and is the same factor used as multiplier on the organic matter decomposition rate However the effect of temperature and moisture on the rates of physic chemical processes driving phosphate ion transfer between inorganic pools is very different from the effect on biological and biochemical processes which involve the decomposition or transformation of organic P compounds or the assimilation of inorganic P into organic pools Rates of biological/biochemical processes governed by microorganisms often double for each 10°C rise in temperature but there exists no verification that similar rules apply for such processes in soil systems Rates of P uptake by plants may be expected to exhibit a Michaelis Menten dependence modified by moisture and temperature although factors controlling supply of P to the root surface (diffusion water flow P solution concentration etc) may be more important in controlling uptake than influx kinetics

Sorption equation The equilibrium relationship between labile P and sorbed P is described in the model in terms of an equation involving coefficients for sorption affinity (sorpaf) and sorption maximum (sorpmx) Thus according to the model s source code (version 4 0) the amount of labile P is calculated as

$$c = 0\ 5 * sorpmx * (2\ 0 - sorpaf) \qquad [2]$$

$$b = sorpmx - (labile\ P_t + sorbed\ P_i) + c \qquad [3]$$

$$labile\ P_t = 0\ 5 * \left(-b + \sqrt{b^2 + 4 * c * (labile\ P_t + sorbed\ P_i)}\right) \qquad [4]$$

The theoretical basis for choosing this formulation is not clear and it seems to bear no relationship with standard ion adsorption equations such as those of Langmuir or Freundlich Furthermore methodologies for characterizing the relationship and defining the coefficients are not documented in the model

Fraction of labile P_i available to the plant In the CENTURY model the fraction of labile P that is available for plant uptake has been formulated as a linear function of the mineral N pool size (higher P availability at higher mineral N levels) delimited by a minimum and a maximum available fraction No explanation is given for this very unconventional relationship In strongly sorbing soils P availability is mainly determined (apart from plant rooting characteristics) by physicochemical processes and a dependence on mineral N availability is very unlikely Moreover as plant production on these soils is generally P limited instead of N limited such a relationship does not apply

Residue partitioning between structural and metabolic pools The partitioning of plant and animal residues between the metabolic and structural residue pools is formulated in the model as a linear function of the lignin nitrogen ratio (L N)

Fraction of residues going into metabolic pool = 0 85 0 018*L N [5]

This relationship is based on data from a large number of plant residue analyses separating cellulose and lignin as structural components from water soluble metabolic components However plants from the infertile South American savanna soils have developed nutrient conserving strategies by rapidly lignifying and L N ratios in plant residues can be so high that the metabolic fraction as calculated with this equation becomes negative Clearly the relationship cannot be used for residues with such high L N ratios

One may also wonder whether it should be expected at all that such a relationship exists In systems which are strongly P limited such as natural savanna vegetation on tropical Oxisols and Ultisols a relationship which is based on the N content of plant or animal residues seems not very logical

Nutrient contents of structural and metabolic pools When partitioning residues between the metabolic and structural pools the latter is assigned a fixed C P ratio of 500 leaving the remaining residue P for the metabolic pool However in analyzing leaf and root litter from grasses legumes and rice on an Oxisol in the Colombian savannas whole litter C P ratios up to 2700 were found In the CENTURY model this would result in negative P concentrations in the calculated metabolic fraction For nitrogen similar problems exist be it in a less extreme from

In principle the option exists in the model to modify the C P or C N ratios of the structural material However in order to cover the most extreme values reported above a C P ratio of around 3000 would be needed No experimental data are available to assess how realistic such a value is and how it varies among species soil conditions seasons etc Increasing such an important input parameter six fold without any supporting data clearly brings into question the reliability of the partitioning of organic P inputs in the model

Structure of the organic P submodel g The pools and flow structure of the organic matter submodels of CENTURY are the same for organic carbon nitrogen and phosphorus the three being linked via C N and C P ratios Such a structure implies that organic C N and P are stabilized and mineralized in the same way the size of the flows relative to each other depending only on the nutrient content of the decomposing material and the potential immobilization of inorganic nutrients However it has been suggested that organic C and N are stabilized together and mineralized through biological processes whereas P may be stabilized independently of the main organic moiety and mineralized through biochemical processes This hypothesis is supported by data on phosphorus fractionation and microbial biomass from Oxisols in Colombia (Table 20)

Table 20 Nutrient content of various fractions from a sequential P fractionation and of microbial biomass in an Oxisol under native savanna

Soil fraction	P §	P §	C	C/P §†	C/P_t §†	C/N†
	= = = = = µg g¹ = = = = =					
Water/resin	2 1	1 5	510	358	*	10 5
$NaHCO_3$	1 5	13 2	1770	137		9 9
NaOH	13 9	53 6	6080	111		13 4
HCl	0 7			*		
HCl hot	68 0	16 7	2670	219		7 4
Residue	45 9		8800	*	191	36 5
Whole soil	86 2		19830	237	91	17 1
Microbes	9 6		470	*	50	9 3

§ P P and P = inorganic organic and total phosphorus

† The ratio averages were calculated as geometric means of treatments so values may differ from those calculated by dividing the individual element means

The organic matter collected in the water fraction after resin extraction as first step of the sequential P fractionation can be considered as easily decomposable and should thus be part of the active SOM pool The same may hold for the organic matter in the $NaHCO_3$ fraction For the Colombian Oxisol of Table 20 these two fractions together contain *ca* 2280 μg C and 15 μg P per g soil The active SOM pool is often estimated as two to three times the amount of microbial biomass so as to also account for microbial metabolites Using the microbial biomass data of Table 20 this would mean an active SOM pool of 940 1410 μg C and 19 29 μg P per g soil The two estimation methods for the active SOM pool thus yield quite different results especially concerning the C P ratios of the material (137 358 when estimated according to the sequential P fractionation and 50 according to the microbial biomass estimate) This makes it doubtful whether indeed the microbial biomass and the easily extractable organic matter from the sequential fractionation can be considered to form one pool with one common turnover rate In the model a C P ratio between 30 and 80 is suggested for the active SOM While the microbial C P ratio falls within this range it is far too low for the H_2O or $NaHCO_3$ extractable fractions The very high C P ratios of the extractable fractions indicate that their decomposition may be largely governed by biochemical rather than microbial processes It may thus be too restrictive to calculate organic P flows in the same way as organic C and N flows

Conclusions and recommendations

Whereas in soils from the temperate zone N is generally the plant growth limiting element many tropical soils are strongly P limited For modeling SOM dynamics this implies that accurate representation of the P and P pool structures and transfer kinetics is crucial for the model s application to such soils The structure of the organic P section of CENTURY is based on the hypothesis that organic P and organic C are stabilized and mineralized together in an kinetically identical manner This hypothesis is questionable The basic structure of the model s inorganic P section is largely in agreement with experimental data but the various equations used lack theoretical justification or do not appear to be based on current knowledge of processes and kinetics Both sections suffer from the fact that it is virtually impossible to properly estimate pool sizes and rate parameters even if detailed soil P fractionation data are available

Several of the equations used in the model for estimating the partitioning between P pools are based on data from a limited range of soils in the temperate zone Applying these to soils with strongly different characteristics as *e g* many tropical soils results in extrapolative calculations beyond the range for which the relationships were tested This can (and does) lead to totally erroneous results

We conclude therefore that great care should be exercised in using the CENTURY model for tropical low P soils This is of special importance to the participants of the Tropical Soil Biology and Fertility Program and the Slash & Burn Project both of which adopted the model for their organic matter studies in the tropics We recommend the following research imperatives with respect to the P submodel

1 Data are urgently needed to build up a database which would allow us to equate P fractions with P pools both organic and inorganic Besides chemical P fractionation isotopic dilution kinetics should be used to obtain information on the intensity quantity and buffer capacity of diverse soils with respect to available P Biological parameters related to P dynamics such as microbial biomass P turnover or phosphatase activity

should also be included in this database

2 Pools are linked by transfer rates whose present model values were estimated using data from a temperate zone soil P database There is a need to determine transfer rates for a range of soil types both temperate and tropical to assess whether the use of universal values is appropriate As the present values were partly approximated through a trial and error approach their estimations could be improved considerably by using tracer studies despite the fact that measurements with ^{32}P and ^{33}P are limited to a maximum period of about 3 to 6 months Such studies would at the same time give information about organic P turnover rates

3 The theory that P is stabilized and mineralized independently of the main organic moiety would have important implications for the basic structure of the P submodel Incubation studies assessing C N and P mineralization in the same samples are required to test this hypothesis

4 The well known ability of microorganisms to adapt to changes in environmental conditions could imply that the range of microbial C P ratios found in low P soils is higher than that commonly found in non P limited soils Results obtained on Colombian Oxisols indicate that this indeed might be true More data on this subject are needed

5 The concentration of organic P in the soil solution of a tropical Oxisol may be much higher than the concentration of inorganic P which with the high amount of rainfall in humid tropical zones is likely to result in P leaching Although this option does exist in the model very few experimental data are available to quantify the importance of such a P flow It is suggested therefore to include the measurement of dissolved P flows in leaching and runoff studies

Dynamics and Short Term Effects of Earthworms in Natural and Managed Savannas of the Eastern Plains of Colombia *M Fisher (TL) J J Jiménez (U Complutense) T Decaens (U Paris) A G Moreno (U Complutense) J P Rossi (ORSTOM/U Paris) P Lavelle (ORSTOM) R Thomas (TL)*

Introduction

Studies on soil biology (especially macrofauna) were initiated at the CORPOICA CIAT Carimagua Research Station on the Colombian Eastern Plains in July 1993 The work started with a preliminary survey of soil fauna communities in contrasting land facets and production systems using the basic TSBF methodology (Decaens 1994) The survey was followed by the initiation of more detailed studies of taxonomy of the species involved and the dynamics of their populations including monitoring of the culticore experiment

Objectives

The main objectives of the program in the long term are

To evaluate the diversity and ecological functions of earthworm species present in the area and

describe the dynamics of their communities in order to
manipulate earthworm communities to improve the productivity and sustainability of agrosystems derived from the native savanna

A series of intermediate objectives were identified
Evaluate the impact of different types of land use on the abundance and structure of soil macrofauna communities
Describe the spatial and temporal patterns of earthworm community structure in the native savanna and in contrasting management systems
Describe the dynamics of recolonization of earthworm communities in a succession of annual crops and improved pastures
Quantify the effect of earthworms on parameters of soil function such as selective ingestion of organic and mineral particles and release of assimilable N and P in casts

Rationale

Earthworms are a dominant component of soil macrofauna in natural savannas and derived pastures and cultures at Carimagua (Table 21) Earthworm biomass (EB) however is significantly lower in these ecosystems than in many other comparable ecosystems In the gallery forest EB is 3 4 g fresh weight m^{2} which is similar to that at Lamto Ivory Coast but lower than in tropical rainforests of America (8 7 g f w m^{2}) EB in native savannas at Carimagua (30 5 g f w m^{2}) is lower than at Lamto while in most grazed savannas EB is less than 10 g fresh weight m^{2}

Improved pastures have much higher EB with a maximum value in *Brachiaria decumbens* and *Pueraria phaseoloides* association (41 2 g fresh weight m^{2}) comparable to other tropical regions i e in Mexico (35 8 to 55 5 g fresh weight m^{2}) and in India (30 2 to 56 g f w m^{2}) The increasing amount of pasture and legume production and nutrient supply of cattle faeces provides the necessary energy to support earthworm populations at higher levels

In rice crops EB is drastically reduced (2 3 g f w m^{2}) as is commonly observed in annual tropical crops due to the use of pesticides the reduction of soil organic matter and the physical effects of soil tillage

It is therefore important to understand the dynamics of these changes and their impact on such basic processes of soil fertility as well as on soil organic matter dynamics and soil physical structure

Research Program

The planned research comprises

1 A rapid sampling of earthworm communities twice a year to draw maps of the spatial distribution in the CULTICORE experiment at the different stages of succession It will be possible to follow the spatial (within and across plots) and temporal (across seasons and alternating types of land use) patterns of the dynamics of earthworm communities

Table 21 List of species of earthworms found in different ecosystems at Carimagua

Species	Family	Location[†]	Ecological category[‡]
Andiodrilus sp	Glossoscolecidae	NS IP GF	Endogeic
Andiorrhinus sp 1	Glossoscolecidae	NS IP	Endo anecic
Andiorrhinus sp 2	Glossoscolecidae	NS	Endo anecic
Martiodrilus sp 1	Glossoscolecidae	NS IP	Anecic
Martiodrilus sp 2	Glossoscolecidae	CG	Anecic
P corethrurus	Glossoscolecidae	AP	Endogeic
Small polyhumic 1	Glossoscolecidae	NS IP GF	Endogeic
Pheretima sp	Megascolecidae	CL	Epigeic
Dichogaster sp 1	Octochaetidae	NS IP	Epigeic
Ocnerodrilidae 1	Ocnerodrilidae	NS IP	Endogeic
Epigeic 1	?	NS IP GF	Epigeic
Epigeic 2	?	CL	Epigeic
Epigeic 3	?	GF	Epigeic

[†] NS native savanna IP improved pasture GF gallery forest AP African palm culture CL Carimagua lake CG Cano Gloria near Carimagua

Anecic live in the soil but feed on the soil surface Epigeic live and feed on the soil surface Endogeic live and feed in the soil

2 An accurate 15 month sampling of natural populations to detail their demographic parameters and seasonal and spatial dimensions of these dynamics Two different types of land use are compared the native savanna and the association legume pasture (*Brachiaria decumbens* + Kudzu) chosen because of the previous survey results (Decaens 1994) (Figures 23 and 24)

3 Studies under laboratory conditions of several aspects of earthworm ecology The different species are cultured to measure growth rate fecundity mortality ingestion of soil organic and mineral particles Studies on N and P dynamics are being carried out in collaboration with two thesis students of the Universidad Nacional Palmira R Thomas and D Friesen

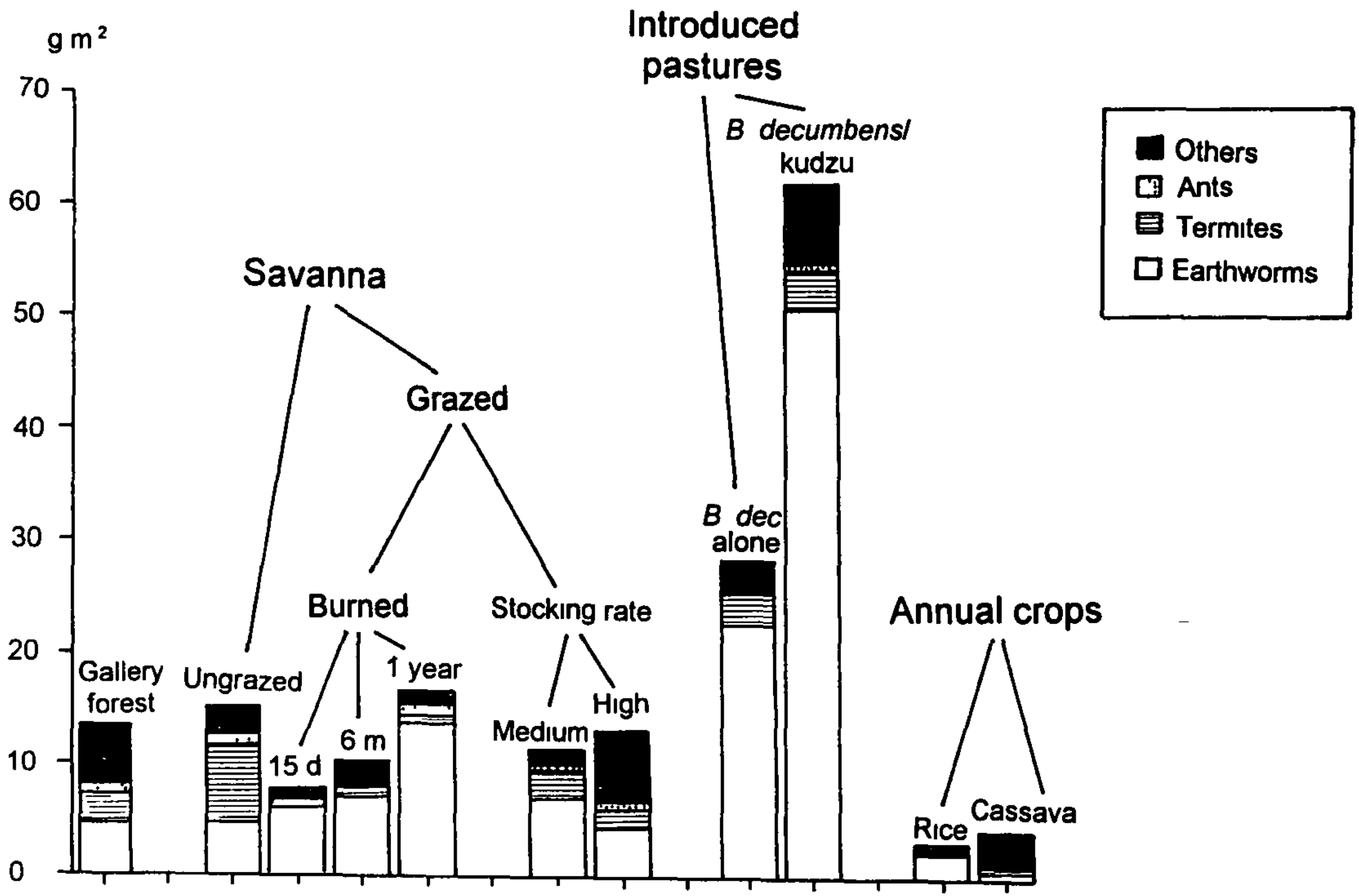


Figure 23 Total biomasss of soil macrofauna under different types of land use at Carimagua

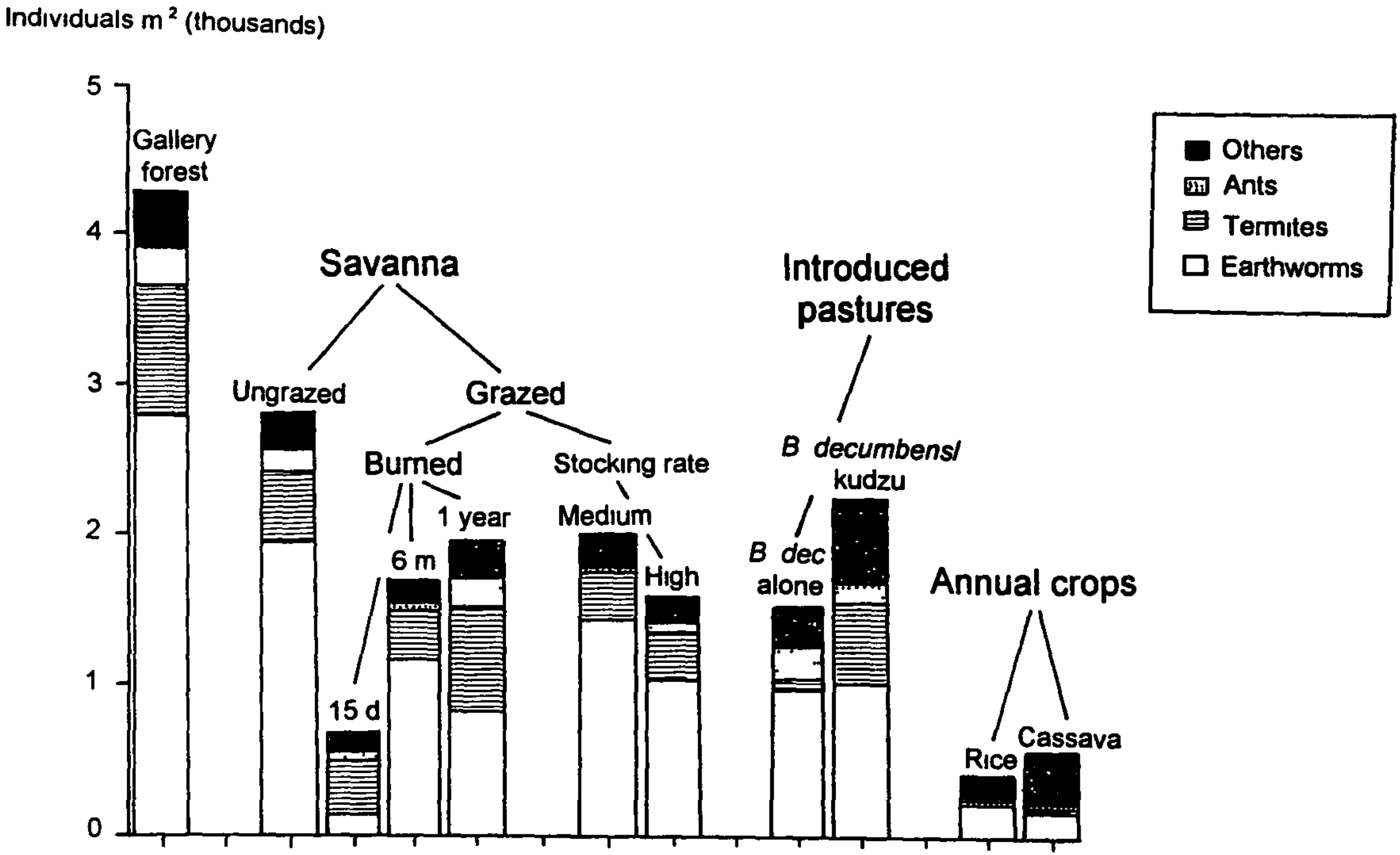


Figure 24 Total density of soil macrofauna under different types of land use at Carimagua

These three detailed studies will define the impact of earthworms on total ecosystem function They will also explain effect of land management on the density and variations in different species of earthworms

RESULTS

a) Taxonomy

The biodiversity of the study site is very important So far 10 to 15 species have been found the doubt arising because not all species have been positively identified (Table 21) The taxonomic study includes natural and managed savannas as well as the gallery forest

The native savanna has eight species while the legume grass association has seven Although the latter system is a disturbed one the biodiversity seems not to be affected much These pastures are now 15 years old and while it is likely that there was a drastic decrease of soil fauna (especially earthworms) when they were established the biomass of earthworms in them is now the highest recorded in Carimagua principally due to a large population of *Martiodrilus* sp 1

The most important species under study are

Martiodrilus sp 1 (sp nov ?) A large (up to 30 cm in length) dark grey species Approximately 10 to 15 individuals m^2 and maximum weight for an adult is 25 g (fresh weight)

Andiorrhinus sp 1 (sp nov?) Up to 30 cm in length also but thinner than *Martiodrilus* Light grey in color less than 10 individuals m^2 and maximum adult weight of 15 g

Andiodrilus sp (sp nov?) No more than 14 cm in length without pigmentation Up to 10 individuals m^2 no more than 6 g maximum weight for an adult

Small polyhumic (sp nov ?) 5 6 cm in length without pigmentation More than 100 individuals m^2 maximum adult weight about 0 20 g

Epigeic 1 (sp nov ?) 5 6 cm in length dark red pigmentation on the dorsal part of the body No more than 20 individuals m^2 maximum adult weigh of 0 15 g

Ocnerodrilidae (sp nov ?) 2 3 cm in length without pigmentation 20 30 individuals m^2 maximum adult weight 0 015 g This species lives and feeds on the casts that fill the long and large galleries of anecic species such as *Martiodrilus* where there is much higher quantity organic matter than in the surrounding soil

b) Population dynamics

Since October 1993 the improved pasture system has been sampled to determine the population dynamics of the earthworm community (Table 22) Similar studies were started in the native savanna in March 1994 The experimental design consists of excavating five 1 m^2 quadrats to 50 cm depth in both systems and handsorting the macrofauna in the field The sample is subdivided into five strata in 10 cm increments All earthworms in the samples are placed in 10% formaldehyde and later separated in the laboratory into species and the adults juveniles and cocoons counted and weighed

Table 22 Density and biomass of earthworms in native savanna and a fifteen year old introduced pasture between October 1993 and May 1994 (n = 5 samples/system/month)

Month	Native savanna		Introduced pasture	
	Density individuals m^{2}	Biomass g fresh wt m^{2}	Density individuals m^{2}	Biomass g fresh wt m^{2}
1993				
October			135	18 1
November			86	21 8
December			38	16 2
1994				
March	25	0 8	46	53 7
April	107	10 3	102	77 6
May	111	9 4	216	110 0

Andiodrilus and *Andiorrhinus* apparently have no strategy or resistance form so their populations were greatly reduced and the survivors initiated reproduction early in the wet season (generally in May)

The soil was very hard during January and February and regular sampling was abandoned Nevertheless a limited sampling of one $1m^2$ quadrat to 110 cm was done in the introduced pasture in February after two months without rain to determine the different strategies used by the different species during the dry season The mean soil water content was about 15 % on a dry soil basis

All of the small polyhumic Glossoscolecidae were in cocoons which allow them to resist the adverse moisture conditions The whole population of *Martiodrilus* was in diapause apparently obligatory all the adults and juveniles rolled up in aestivating chambers as much as 90 cm deep in the soil This special characteristic of an anecic (soil living but surface feeding) species allows them to reduce otherwise high mortality during the unfavorable conditions of the dry season Large (25 mm length) cocoons from which the young would subsequently emerge comprised the greater part of the population These were mainly in the 30 40 cm stratum in contrast to the juveniles and adults at greater depth

The number of individuals in the early wet season (March May) was not greatly different between the native savanna and the introduced pasture but there was more than a tenfold increase in biomass in the latter compared with the savanna (Table 23)

Table 23 Mean density and biomass of earthworms in native savanna and introduced pasture over three months March April and May 1994

Native savanna		Introduced pasture	
Density individuals m 2	Biomass g fresh wt m 2	Density individuals m 2	Biomass g fresh wt m 2
81	6 8	121	80 4

Another difference between these two systems is related to the number of turriculated casts which are the tower like spiral casts deposited over the soil surface by earthworms At Carimagua these structures are produced by *Martiodrilus* and they may be up to 10 cm in height Table 24 shows the number of turriculated casts in the native savanna and in the improved pasture

Table 24 Number of turriculated casts in ten 1 m^2 random samplings in the native savanna and introduced pasture at the beginning of the wet season at Carimagua

Condition	Native savanna	Introduced pasture
Dry	91	268
Fresh	2	40
Dry base/fresh	3	59

Fresh casts indicate a real presence of an individual of *Martiodrilus* and may be taken as evidence of activity of this species The improved pasture system presents a production of fresh casts about 20 times greater than the native savanna which appears to be consistent with the biomass data

c) Laboratory studies

Cultures of the major species have been done under laboratory conditions to evaluate their soil ingestion rates (using basic methodology) and then extrapolate these data to field conditions Knowledge of the overall annual earthworm community population allow us to estimate the total soil ingestion of this community per year and per hectare

The two species *Andiodrilus* and *Martiodrilus* have the greatest intake of soil at a water content of 34 % on a dry soil basis that is near pF 2 5 equivalent to field capacity The global consumption on a yearly basis requires data on the population dynamics throughout the year which is not yet available Over the 6 month period October to April the global consumption of a population of *Andiodrilus* is about 70 t dry soil ha 1 and for *Martiodrilus* is nearly 400 t dry soil ha 1 (Table 25) The numbers could be expected to be more than double when the whole wet season is included

Table 25 Soil ingestion rates and global consumptions of two species of earthworms from Carimagua

Species	Soil ingestion rate[†] g dry soil day [1]	Global consumption[†] t dry soil ha [1] 6 months [1]
Andiodrilus	5 4	70
Martiodrilus	21 3	390

[†] At soil water content of 34 % on a dry soil basis

d) Spatial distribution of communities (GEOSTATISTICS)

A preliminary sampling has been done in the *Brachiaria decumbens/ P phaseoloides* (Kudzu) pasture (September 1993) using an experimental design consisting of 64 40x40x15 cm samples taken every ten meters on a 70x70 grid Of the major species distinguished only populations of the small polyhumic Glossoscolecidae had a spatial structure These populations had a distribution in patches a few tens of meters in diameter with distinct patterns for adults and juveniles The experimental design did not allow the definition of structures in other populations possibly due to their low densities By November 1994 there were substantial changes in the spatial distribution (Figs 25 27)

Geostatistics have also been applied observations of distribution of turricules at the soil surface as an indirect measure of populations These data correspond well with those of excavated samples and confirm the patchy population distribution The next step is to determine whether environmental factors regulate the patchiness or if demographic factors are responsible

Carbon storage deep in the soil by introduced pastures in the South American savannas
M Fisher R Vera I Rao J Sanz C Lascano R Thomas M Ayarza L F Chávez (TL)

The terrestrial biosphere appears to take up part of the anthropogenic carbon dioxide emissions about which there is increasing concern and awareness because of its possible consequences While much of the increase of atmospheric CO_2 caused by agriculture in the last few decades is widely blamed on changes in land use in the tropics we report here that introduced pastures based on deep rooted grasses in the South American savannas can accumulate organic carbon at depth in the soil These grasses were introduced and selected by the Centro Internacional de Agricultura Tropical (CIAT) emphasizing deep rootedness principally for extraction of calcium and other nutrients and for better exploitation of soil water to maintain green forage during the 3 5 months dry season The amount of carbon sequestered could be as high as 507 million tons (Mt) carbon a year which could account for part of the missing global carbon sink of 0 4 4 3 billion tons (Gt) The discovery of this amount of carbon sequestration in tropical savanna soils represents an immediate and effective alternative in efforts to combat the threat of global warming with the added advantage of increased agricultural production on soils of low fertility

A

B

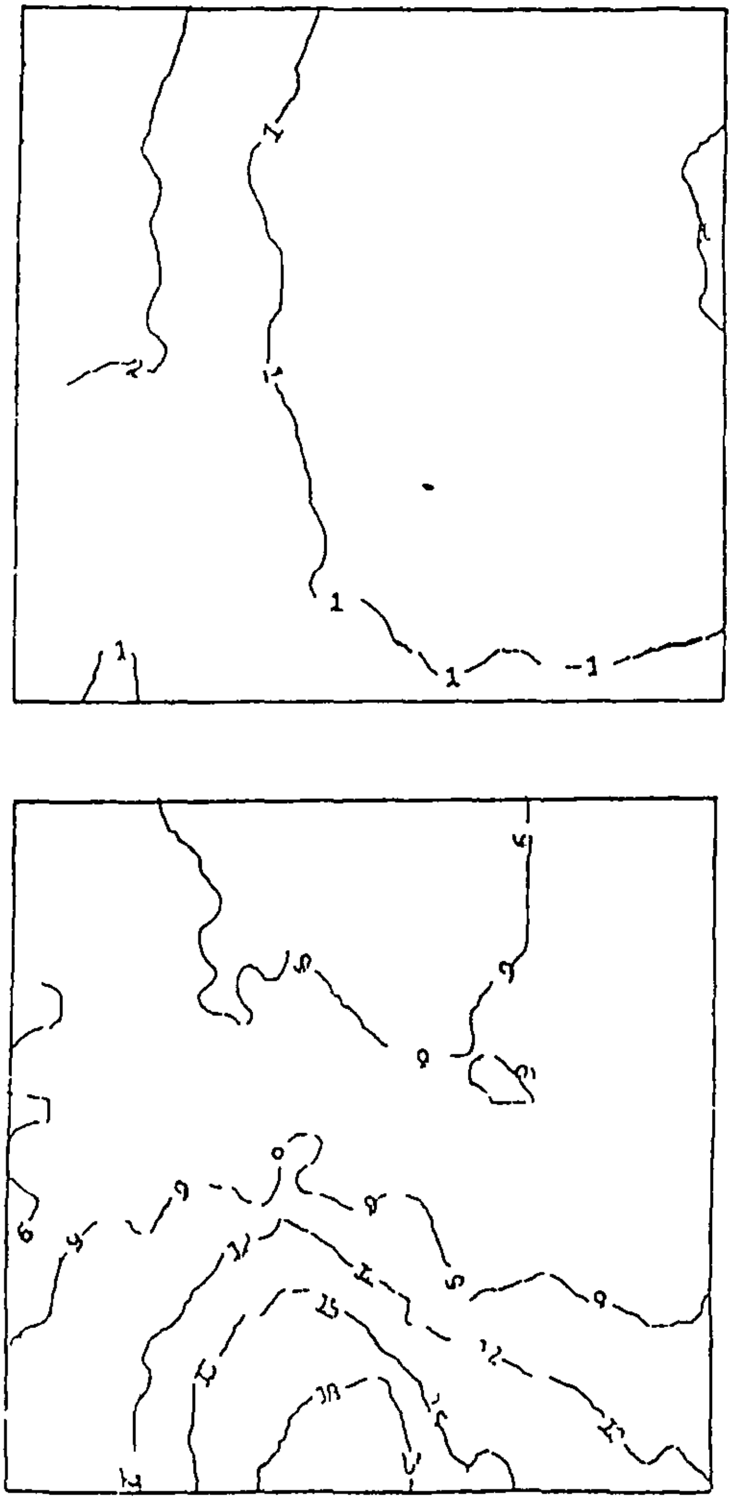


Figure 25 The distribution of a polihumic species of Glossoscolecidae earthworm in a fifteen year-old *Brachiana decumbens*/kudzu grazed pasture at Carimagua in September 1993 A adults B juveniles The contours link sites with the same density (figures are individuals m^{-2}) The surveyed area measured 70 m a side

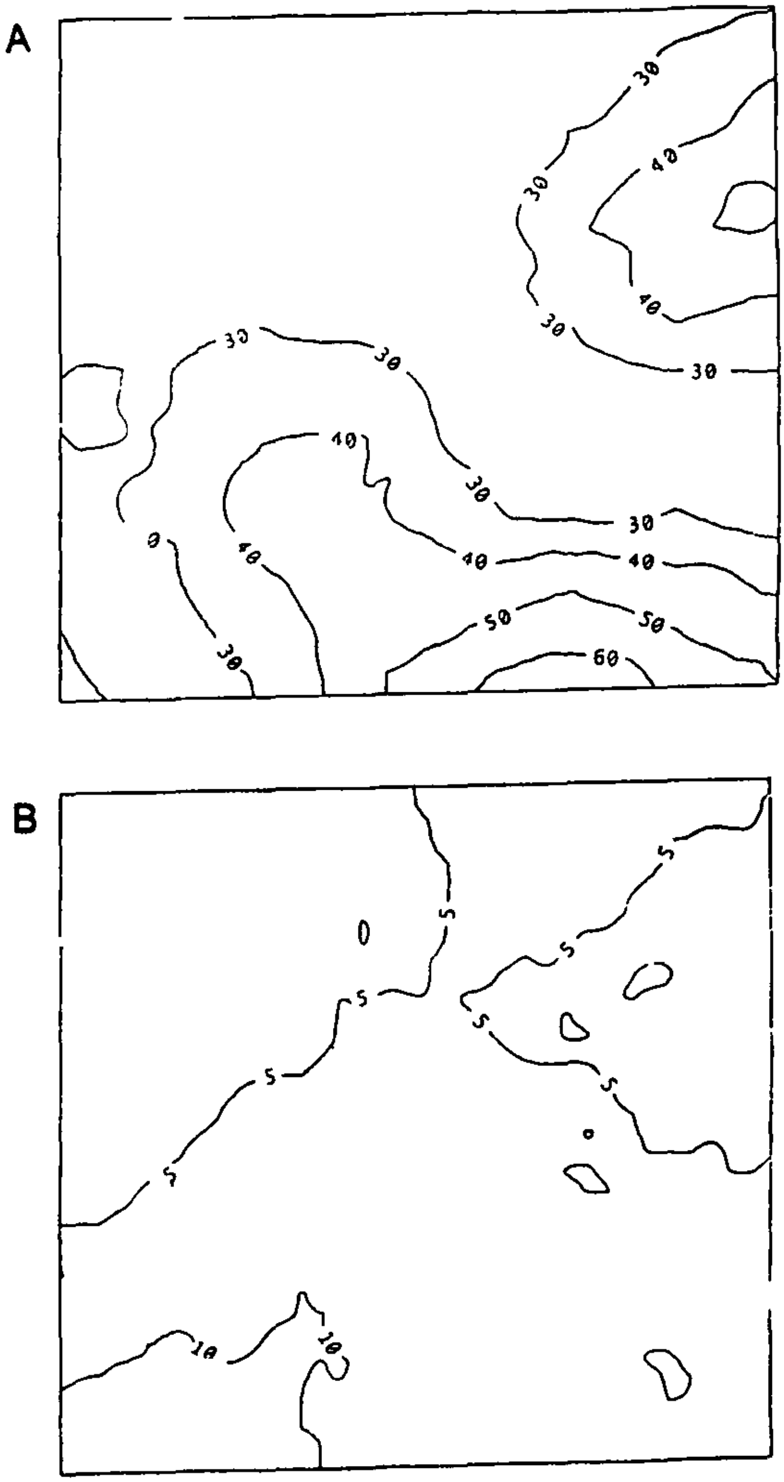


Figure 26 The distribution earthworms in a sixteen year-old *Brachiana decumbens*/kudzu grazed pasture at Carimagua in October 1994 A distribution of juveniles of a polihumic species of Glossoscolecidae B distribution of fresh surface casts of *Martiodrilus* spp The contours link sites with the same density (figures are individuals or casts m^{2}) The surveyed area measured 70 m a side

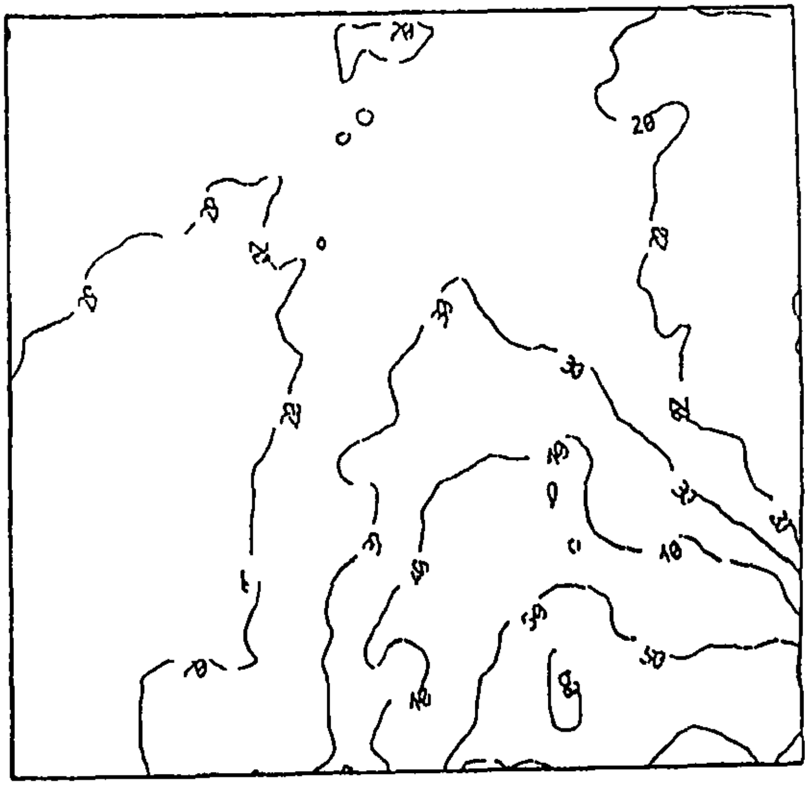


Figure 27 The distribution of the juveniles of a polihumic species of Glossoscolecidae earthworm in an ungrazed native savanna at Carimagua in November 1993 The contours link sites with the same density (figures are individuals m^{-2}) The surveyed area measured 70 m a side

Savannas occupy some 250 million hectares (M ha) of South America mainly in Brazil (200 M ha) Colombia (20 M ha) and Venezuela (12 M ha) They are used for extensive cattle ranching on the native forage although in Brazil cropping with maize and soybeans (now 12 M ha) and introduced pastures (35 M ha) have become important during the last 30 years The soils of the savannas are mainly oxisols and ultisols characterized by low pH s (4 0 4 8) aluminum saturation up to 90% and low levels of P and Ca Rainfall is 1500 3000 mm with a unimodal seasonal distribution

The perennial grasses *Andropogon gayanus* and *Brachiara humidicola* are of African origin *A gayanus* is tall growing with a tussock habit while *B humidicola* forms swards The legumes *Arachis pintoi* and *Stylosanthes capitata* are from South America *A pintoi* is a vigorous stoloniferous perennial and *S capitata* is a free seeding biannual Grass legume associations of these forages produce cattle liveweight gains up to 500 kg ha^{1} yr^{1} compared with 7 20 kg ha^{1} on well managed savanna They produce green forage for several months into the dry season and regrow vigorously soon after the opening rains of the wet season Since 1980 all four have been released as cultivars in one or more countries in South America There are now 7 M ha planted to *A gayanus* in Brazil alone (M A Ayarza personal communication)

Although deep rootedness is considered a major factor in adaptation to low fertility soils especially in *A gayanus* the role of the roots in the dynamics of soil carbon has largely been ignored We measured soil carbon in an *A gayanus* pasture and in two *B humidicola* pastures at two sites on the eastern plains (llanos) of Colombia some 200 km apart (Table 26) In each case we obtained corresponding measurements for the native savanna

The pastures had differing histories (Table 26) but all had carried grass based pastures for three to nine years The pasture at Matazul farm was not fertilized after the rice that was used as a pioneer crop to establish it while at Carimagua fertilizer was applied at pasture establishment and each second year thereafter They were all grazed by cattle at normal stocking rates for improved pastures in the region

All the grass based pastures made a striking contribution to soil C compared with the native savanna especially when grown with a legume (Table 27) Data for other pastures based on another grass of African origin *Brachiaria dictyoneura* cv Llanero at Matazul farm show lower but still significant fixation of about 30 t C ha^{1} in 3½ years (data not presented) If these data are representative of the areas sown to pastures of *A gayanus* and *Brachiaria* species in South America conservatively estimated at 35 Mha then from 100 to as much as 507 Mt C is being sequestered each year

The contribution of the legume in the six years since its establishment at Carimagua may be estimated by taking the difference between the grass alone and the association The difference is 44 7 t C ha^{1} so that although legumes contribute only about 15% to root biomass the association with *A pintoi* increased carbon fixation by 7 8 t ha^{1} yr^{1} compared with the pure grass

Compared with the savanna the grass based pastures sequester most of the C in the deeper part of the soil profile well below the plough layer (normally 10 15 cm) This C should therefore be less prone to oxidation and hence loss during any cropping phase that might be undertaken in integrated crop and pasture systems Indeed such systems should be able to accommodate rotations with annual crops and still contribute to C sequestration Jones *et* *al* drew attention to the role of fire in determining the balance between the vegetation of native savannas as either a net sink or source of carbon in the tropics Introduced pastures are rarely burned except by accident in contrast to the native savannas which are usually burned as often as each year

Table 26 Location and characteristics of the two sites on the savannas of the eastern plains of Colombia

Site	Matazul farm	Carimagua Research Station
Location	Eastern plains (Llanos) Puerto Lopez Colombia	Eastern plains (Llanos) 200 km ENE of Puerto Lopez Colombia
Latitude longitude Altitude (m)	4°9 N 72°39 W 160	4°37 N 71°19 W 175
Mean annual rainfall (mm yr[1])	2 700	2 240
Soil	Oxisol	Oxisol
Texture	Clay loam	Clay loam
pH (1 1 water)	4 4	4 1
P (0 20cm) Bray II (ppm)	1 8	1 5
Pasture details	**1989** Cropped from savanna with upland rice undersown with mixed *A gayanus* cv Carimagua 1 and *S capitata* cv Capica pasture **1989 93** Rotationally grazed with cattle at 2 head ha[1]	**1984** Sown to *B humidicola* cv Humidicola from savanna with the legume *Desmodium ovalifolium* which failed **1987** Resown to *B humidicola* cv Humidicola alone or with *A pintoi* cv Mani Forrajero **1988 93** Rotationally grazed with cattle at 3 head ha[1]
Date soil sampled	December 1992	April 1993

Table 27 Yield and net gain of carbon in grass based pastures compared with native savanna on two sites on the savannas of the eastern plains of Colombia

Methods Each sample comprised eight cores at Matazul and four at Carimagua taken at random by soil auger to the depths indicated In the grazed *A gayanus/S capitata* pastures at Matazul Farm samples were taken from each quarter of each of three 1 ha plots in a randomized complete block experiment covering 9 ha At the same time four samples were taken from the native savanna immediately adjacent to the experiment At Carimagua the grass based pastures were 0 5 ha plots in a randomized complete block grazing experiment Five samples were taken from each of two replicates of the plots and three from the immediately adjacent savanna

The samples were dried and milled to pass a 1 mm sieve Fine roots were not removed before milling Sub samples were digested in sulphuric acid potassium dichromate heated (150 °C) for 30 min on a temperature controlled hotplate Carbon concentration in the digest was determined colorimetrically against calibrated standards made up of carbon free soil to which measured amounts of glucose were added Soil bulk density used to convert the gravimetric figures of soil C to volumetric data was determined by standard methods[25] The data for each depth of each pasture were treated as independent samples and the standard error of each mean and the standard errors of the difference between the means were calculated Differences between the means were tested for statistical significance with Student s *t* test

Site	Matazul Farm			Canmagua Research Station				
Pasture	Savanna	*A gayanus / S capitata*		Savanna	*B humidicola* alone		*B humidicola / A pintoi*	
Depth	Carbon in layer	Carbon in layer	Difference from savanna	Carbon in layer	Carbon in layer	Difference from savanna	Carbon in layer	Difference from savanna
cm	t ha	t ha	t ha ±SE	t ha	t ha	t ha ±SE	t ha	t ha ±SE
0-20	64 0	71 1	7 1± 2 0 **	70 3	76 0	5 7±4 3 ns	88 1	17 8± 4.2 **
20-40	42 7	51 9	9 3± 2 8 **	52.4	57 6	5 3±3 2 ns	71 2	18 6± 6 0 **
40-100 †	79 8	114 2	34 3± 9 3 ***	74 3	89 2	14 9±6 2	108 4	34 0±10 0**
Total	186 5	237 2	50 7±11 4 ***	197 1	222.8	25 7 ±7 7**	267 5	70 4±15 5***

† At Canmagua Research Station the deeper layer was 40-80 cm.
ns P>0 05 P<0 05 ** P<0 01 *** P<0 001 SE – standard error of difference between the means (n=14 for Matazul Farm, n=12 for Canmagua)

There are few data of soil C below 15 20 cm in the tropics although there are occasional figures to 40 cm Long *et al* and their collaborators carried out careful studies on native tropical grasslands to document total primary productivity including roots in the surface 15 cm They showed that productivity of tropical grasslands above ground and below ground to 15 cm was up to five times higher than previously reported mainly because losses due to senescence were ignored On the basis of our data even they may have substantially underestimated root production They did not present data of soil C

Although CIAT s emphasis on deep rooted grasses was for reasons other than sequestration of C we have shown that some introduced grasses in the tropical South American savannas do sequester C deep in the soil There must be a physiological cost in growing such a massive root system but strangely we do not see much evidence of it Both *A gayanus* and *B humidicola* grow at least as vigorously as other promising introduced grasses and much more vigorously than the savanna species

We suggest that the sequestration of C in South American savanna soils is of global importance We suggest that deep rootedness can be exploited from the point of view of both the individual farmer and the community at large for the mutual benefit of both Can the ability of tropical grasses to sequester C at depth especially when grown in mixtures with legumes be used in selection and breeding? What are the implications for the generation of technologies to recuperate degraded pastures in cleared areas of the humid forests? The latter is an emotional issue but there is considerable capacity for these soils too to sequester carbon if they are managed correctly

The combination of a deep rooted grass with a nitrogen fixing legume can increase nutrient cycling greatly improve animal production and markedly increase soil biological activity These effects occur mainly at the soil surface while C storage takes place below the plough layer Thus far from being environmentally degrading improved pastures can fulfill the restorative role in tropical systems that was recognized in pre Roman times for Mediterranean systems and may play a vital part in stabilizing the global C cycle and minimizing the greenhouse effect of atmospheric carbon dioxide

Crop nutritional requirements and input use efficiency on llanos oxisols under crop rotations
D K Friesen (IFDC) J I Sanz D Molina and M Rivera (TL)

The predominant soils of the Colombian Llanos are highly acidic Oxisols and Ultisols whose mineralogy is dominated by kaolinite and the oxides and hydrous oxides of iron and aluminum These minerals impart to 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

The high oxide contents of Oxisols and Ultisols also result in a high clay mineral surface area which strongly sorbs phosphate (P) and gives rise to what is commonly referred to as a high P fixation capacity However there are reports of substantial residual effects of applied P on so called high P fixing soils To maximize P fertilizer use efficiency it is necessary to quantify the residual value of previous P fertilizer applications and to understand the fate of applied P and its rate of movement between important P pools in soil including soil organic P pools which play a pivotal role in P cycling

Because of the ınherent ınfertılıty of savanna soıls and the need to ratıonalıze fertılızer ınputs and maxımıze nutrıent use effıcıency ın the croppıng systems beıng developed by CIAT for the Llanos experıments were establıshed ın 1993 to (1) determıne optımal levels of soluble phosphate fertılızer and optımum rates of lıme potassıum and magnesıum for selected annual crops on contrastıng soıls of the eastern savannas (2) estımate resıdual effectıveness of P lıme K and Mg applıcatıons and requısıte maıntenance rates for optımal crop growth (3) characterıze the fate of P applıcatıons and parameterıze a model of P resıdues ın hıghly weathered soıls and (4) monıtor the dynamıcs of applıed catıons and Al and pH ın the soıl and the ınteractıon of amendments on nutrıent fluxes and fate These experıments have now completed 1 ½ to 2 annual rotatıon cycles Thıs report summarızes both results on ınıtıal crop nutrıtıonal requırements on Llanos Oxısols and acıdıc Inceptısols and prelımınary results on the resıdual effectıveness of fertılızer ınputs

Materıals and Methods

Durıng 1993 experıments were establıshed at three sıtes on the eastern plaıns of Colombıa on loamy clay Oxısols at the Corpoıca/CIAT Research Statıon at Carımagua and the Matazul Farm approxımately 70 km east of Puerto Lopez and on a sandy Inceptısol at La Florıda Farm on the Seranía approxımately 50 km south of Matazul Due to logıstıcal problems the Seranía sıte was abandoned ın 1994 Soıl characterıstıcs at each sıte are summarızed ın Table 28 The experıments are unıformly two crops per year rotatıons of maıze and soybeans or rıce and cowpea The former rotatıon requıres hıgher levels of lıme ınputs due to the greater sensıtıvıty of the germplasm to acıd soıl condıtıons than the latter rotatıon Two types of experıments were ımplemented as descrıbed below

Table 28 Chemıcal characterıstıcs of soıls at the three experımental sıtes

S t	Texture	Org C (%)	Total N (ppm)	Bray P (ppm)	pH (H2O)	Exchangeable Catıons (meq/100g)						Al Satn (%)
						Al	H	Ca	Mg	K	ECEC	
Carımagua	Loamy clay	2.41	1249	1 4	4 26	2 28	0 23	0 09	0 07	0 22	2 89	79 0
Matazul	Sandy clay	1 50	682	1 9	4 40	1 93	0 23	0 12	0 06	0 05	2 39	80 7
La Florıda	Sand	0 80	400	3 1	4 01	0 71	0 08	0 04	0 03	0 14	1 00	70 9

Lıme potassıum magnesıum balance experıment Thıs experıment ıs an ıncomplete factorıal of 5 or 6 levels of calcıtıc lıme (0 150 300 600 1200 kg/ha on rıce 0 400 800 1600 3200 6400 kg/ha on maıze) 4 of potassıum (0 40 80 120 kg K/ha) and 3 of magnesıum (0 30 60 kg Mg/ha) gıvıng a total of 32 treatments set out ın a splıt plot desıgn wıth three randomızed blocks Lıme treatments (maın plots) were applıed once at the ınıtıatıon of the experıments whereas K and Mg treatments are applıed to each crop (½ rates on the legumes) Soıl profıle samples to a depth of 100 cm (0 10 10 20 20 40 40 60 60 80 80 100 cm) are taken from selected treatments annually prıor to sowıng the cereal crop surface soıl samples are taken from all plots prıor to each crop All samples are analyzed for pH exchangeable cations (Al H Ca Mg K) Organic C total N and available P are also monitored in the surface soil

Phosphorus residual value experiment This experiment comprises a total of 16 treatments set out in a randomized block design with 4 replications The treatments consist of 10 rates of P (as TSP broadcast and incorporated at planting) applied once only at the beginning of the experiment and 6 rates applied annually to the cereal crop in the rotations Taken together these treatments fully characterize the P response function in the first year and enable estimation of the residual effectiveness of the initial application in subsequent years Crop observations include response to P fertilizer applications and residual value diagnostic tissue analysis and component analysis to determine P removals and returns via crop residues Soil samples taken prior to each crop will be used to monitor changes in labile P pools as influenced by P fertilizer applications and time Measurements will include labile P by classical soil test methods (Bray and Olsen available P) isotopic exchange and determination of organic and inorganic fractions following the Hedley procedure

In all experiments nutrients not included as treatments (including N S and Zn) are applied at adequate levels All fertilizers (treatments and basal) are broadcast and incorporated prior to planting although N and K applications are split whereby a second and third dressing are applied at 30 and 60 days after planting

Results

Soils at all three experiment sites are highly acidic having a pH (H_2O) in the range of 4 4 5 and an exchangeable Al saturation of 70 80% (Table 28) Soil texture ranges from sandy through to loamy clay with corresponding differences in soil organic C and total N among sites All sites are uniformly very low in available P as measured with the conventional $Bray_2$ extractant

Lime potassium magnesium balance/interactions Lime rates chosen were based on the relative requirements of rice (0 to 1200 kg/ha) and maize (0 to 6400 kg/ha) and the desire to observe the full response curve throughout the anticipated 4 year duration of the experiments Measured some 5 to 8 months after application calcitic lime had very little effect on soil pH at rates of about 1500 kg/ha or less (Figure 28A and 28D) Even the application of 6 4 t/ha to the loamy clay Oxisol at Carimagua did not increase the soil pH above 5 5 an indication of the high acid buffering capacity of this soil Nevertheless lime had immediate and important effects on exchangeable Al and Ca on both soils (Figure 28) Interpolated from the relationship between Al saturation and lime applied (not shown) the standard 300 kg/ha application at Matazul reduced Al saturation to about 70% while 500 kg/ha reduced it to about 60% At Carimagua Al saturation was reduced to about 35% with an application of 2 t/ha of calcite Two sequential soil samplings at Carimagua one season and two seasons after liming showed no noticeable temporal changes in soil pH exchangeable Al or Ca (Figure 28) Clearly a longer time interval is necessary to discern losses of Ca from the surface soil and reduced residual effectiveness of the applied lime

Two rice cultivars (the acid soil tolerant Sabanas 6 line and the susceptible Llanos 5) were sown at Matazul in 1994 on plots which had been limed one year earlier As in the preceding year (see CIAT Savannas Program Biennial Report 1992 1993) Sabanas 6 did not respond to lime (calcite) when adequate levels of K and Mg were also applied and relatively little K (about 40 kg/ha) was required for maximum yield (Figure 29) As evident in the negative interaction Ca (as calcite) and Mg compensated for each other in increasing rice production Thus in the absence of calcite 30 kg Mg/ha resulted in maximum rice grain yields while 600 kg/ha of calcite (about 150 kg Ca/ha) gave maximum yields without Mg application (Figure 29B) Taken together these results suggest that the dominant constraint to Sabanas 6 growth in these soils is Ca deficiency (for which Mg can substitute) rather than Al toxicity In contrast to Sabanas 6 rice LLanos 5 had a significant lime requirement for which Mg was unable to compensate (Figure 29D) Moreover yields of the susceptible Llanos 5 were generally much poorer although It had a higher apparent K requirement than Sabanas 6 (Figure 29C)

Cowpeas were sown after rice on the sandy Inceptisol at La Florida in September 1993 Yields were maximal at about 1 t/ha with as little as 600 kg/ha of lime applied to the rice (Figure 30A) Cowpea also responded markedly to K applications of up to 40 kg/ha while higher rates tended to reduce yields especially at lower lime rates Similar observations have been made with cowpea in Nigeria and are attributed to Al toxicity induced when increasing concentrations of K ions exchange with and displace Al into soil solution As with the preceding rice crop a very significant deficiency in Mg was also observed at La Florida (Figure 30B)

The recently released acid soil tolerant maize line (CIMMYT Sikuani) was planted at Carimagua during the second season of 1993 It produced a maximum yield of about 3 5 t/ha with about 1 5 t/ha of calcitic lime (Figure 31A) This amount of lime reduced the exchangeable Al saturation to about 45% More significant however is the observation that this material produced 2 6 t/ha or 77% of the maximum yield even without lime Response to K was observed up to 80 kg/ha (Figure 31B) but in contrast to observations at the other two sites there was no significant response to Mg at Carimagua (data not shown)

Phosphorus fertilizer response and residual effects Response of rice and cowpea at Matazul and maize at Carimagua to P fertilizer reflect the very low levels of available P in these Oxisols in general virtually no yield was obtained without applied P (Figure 32 and 33) Nevertheless application of P fertilizer produced sharp responses with maximum yields being obtained with 40 60 kg P/ha on rice and 60 80 kg P/ha on maize Cowpea grown on residual P applied to the previous rice crop in 1993 also produced maximum yields at 40 60 kg P/ha (Figure 33A)

Results from the first semester of 1994 at Carimagua and Matazul provide direct comparisons between residual P applied 8 to 11 months earlier to maize or rice and freshly applied P Although comparison of individual treatments which received all P in the previous year with those which received the same amount split between two years suggests a diminishing effectiveness of the older P response to both the residual and annual P application strategies are described by the same response functions These results indicate firstly that P fertilizer requirements of crops on Llanos Oxisols are not excessive and secondly that P applications have potentially substantial residual value

Conclusions

Llanos soils are deficient in most of the major nutrients necessary for crop production and P is clearly among the most limiting nutrients Fortunately germplasm now exists which is reasonably tolerant of the other major agricultural constraint of these soils soil acidity and Al toxicity Relatively modest rates of lime were found to be sufficient to produce maximum yields of rice cowpeas and maize using the advanced germplasm Very preliminary data also suggest relatively small reductions of the effects of lime after a 1 year period Residual effectiveness of P fertilizer on these high P fixing soils also appears to be appreciable However for both lime and P it will be necessary to monitor these effects over a period of several years to quantify the input use efficiency and to determine their fate For phosphorus information of this type will enable the parameterization of models describing fertilizer P residual value and cycling including the CENTURY model which simulates P cycling in agroecosystems It will also assist in the development of the P sub model of the CERES crop simulation models and enable the extrapolation of results to other environments

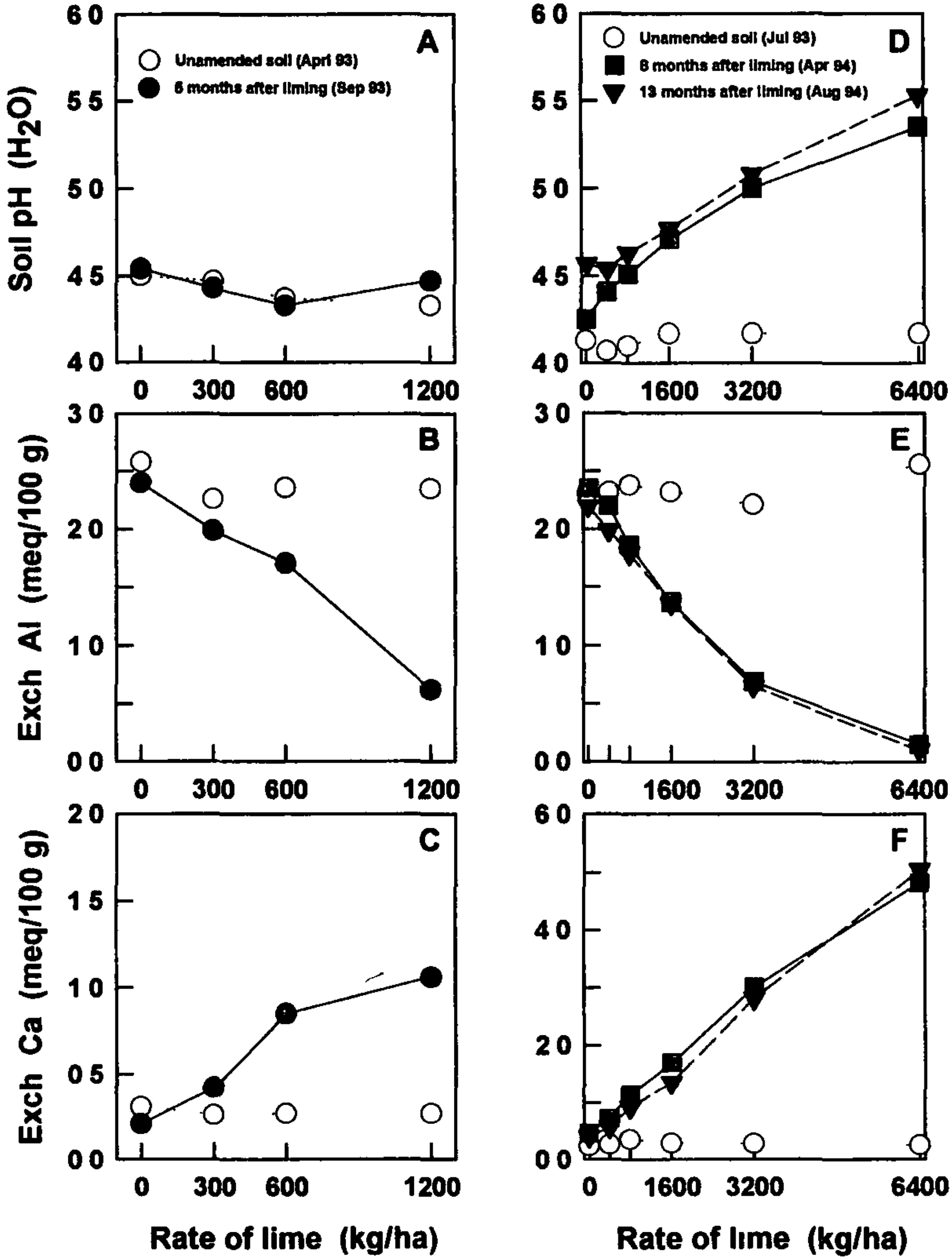


Figure 28 Influence of calcitic lime on soil pH exchangeable Al and Ca in Oxisols at Matazul (A B C) and Carimagua (D E F) and changes in time after application

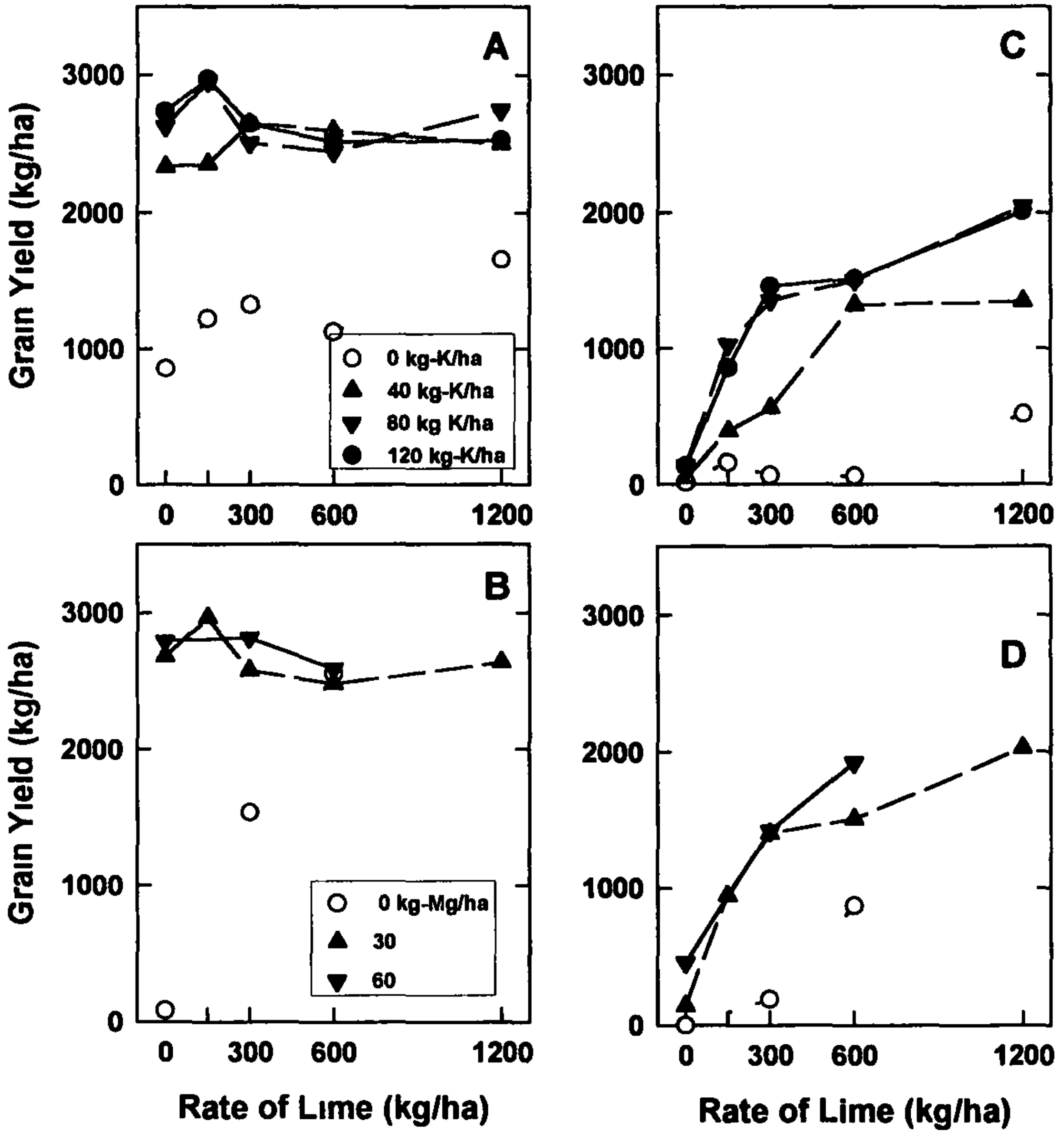


Figure 29 Response of two rice cultivars (Sabanas-6 [A B] and Llanos 5 [C D]) to and interactions of lime (calcite) potassium and magnesium on an Oxisol at Matazul farm (1994)

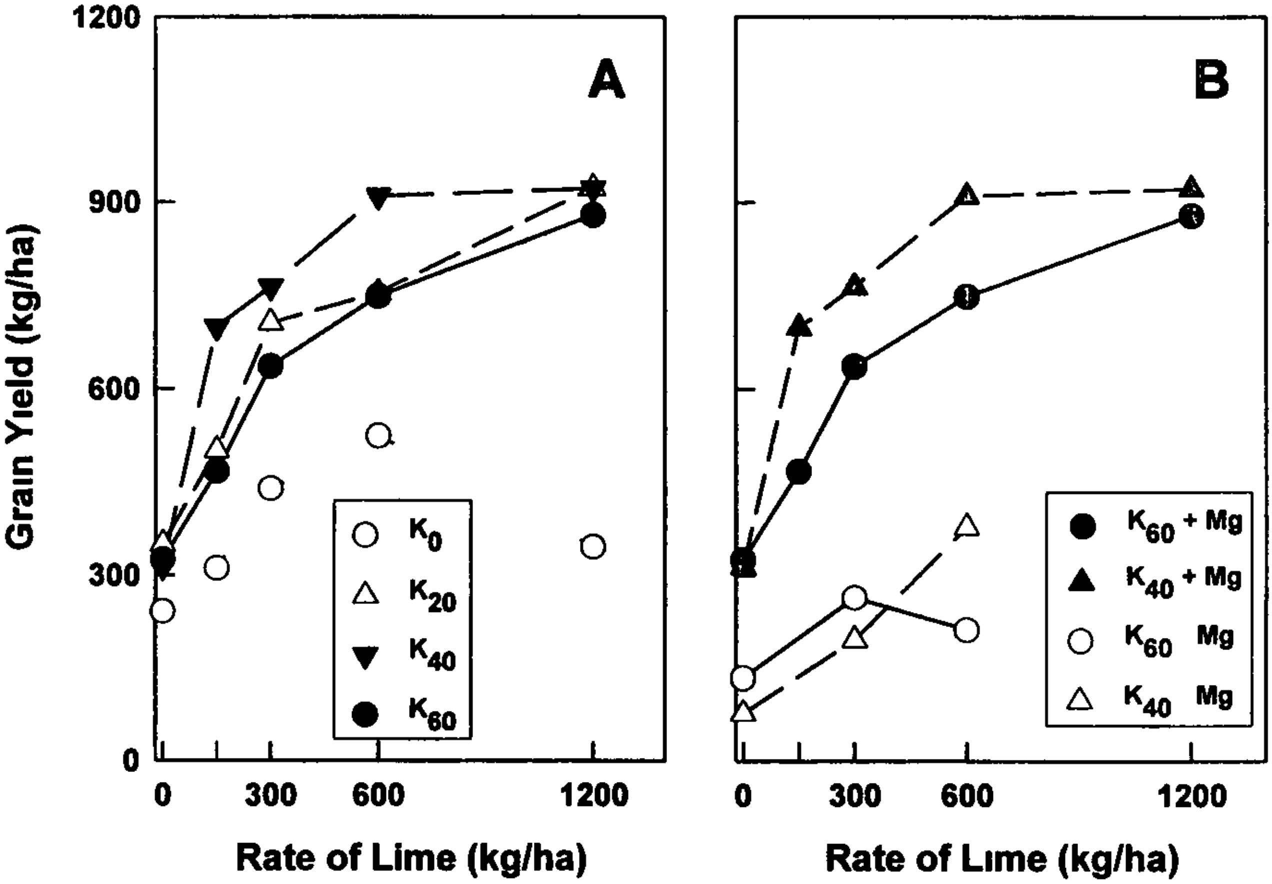


Figure 30 Interactions of (A) lime and K at adequate Mg and (B) lime K and Mg on cowpea yields on a sandy Oxisol at La Florida (1993)

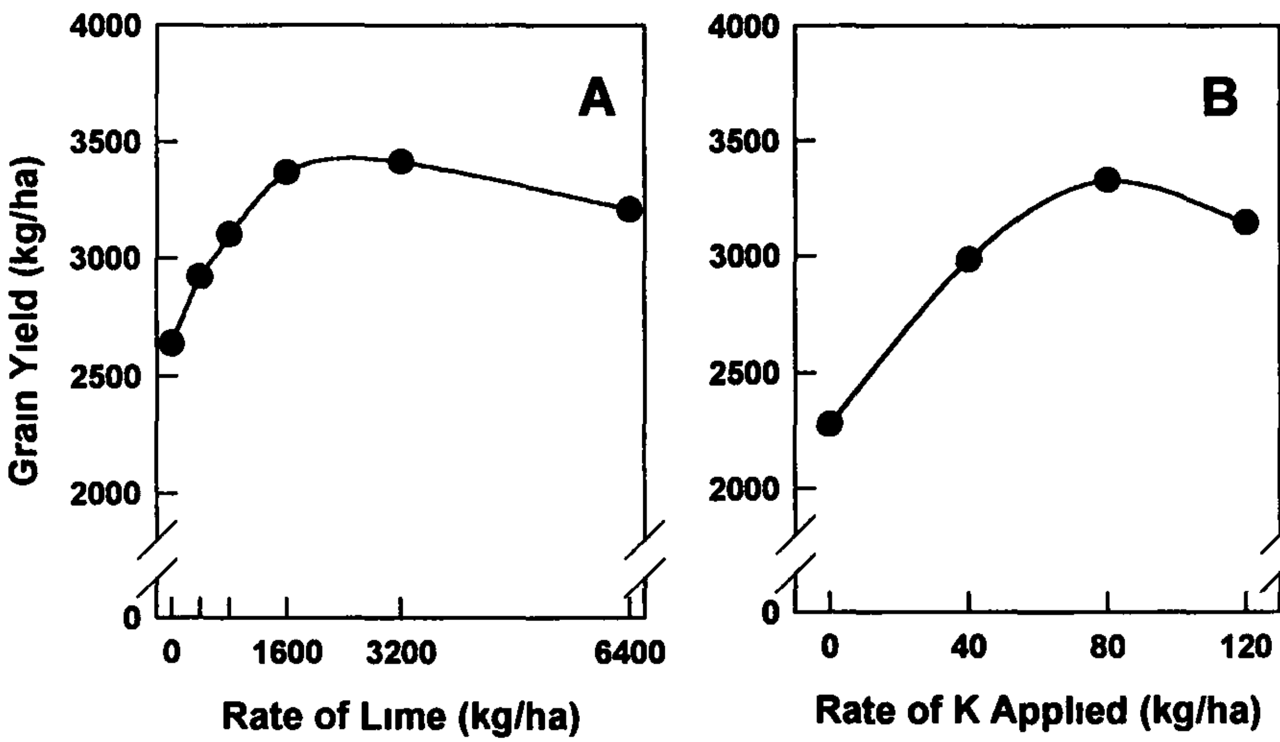


Figure 31 Response of maize (CIMMYT Sikuani) to (**A**) calcitic lime at optimal levels of potassium and magnesium and (**B**) to potassium at optimal levels of lime and Mg

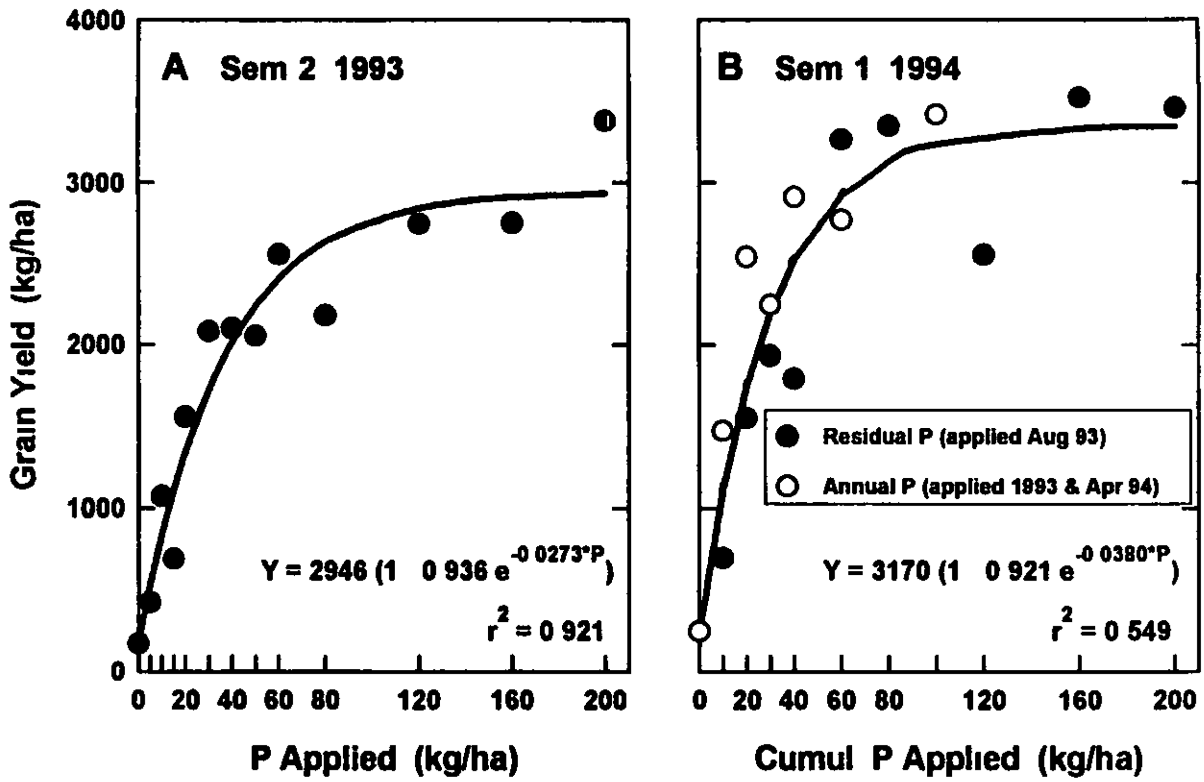


Figure 32 Response of maize (CIMMYT Sikuani) to [A] freshly applied TSP and [B] residual and re-applied TSP on a loamy clay Oxisol at Carimagua

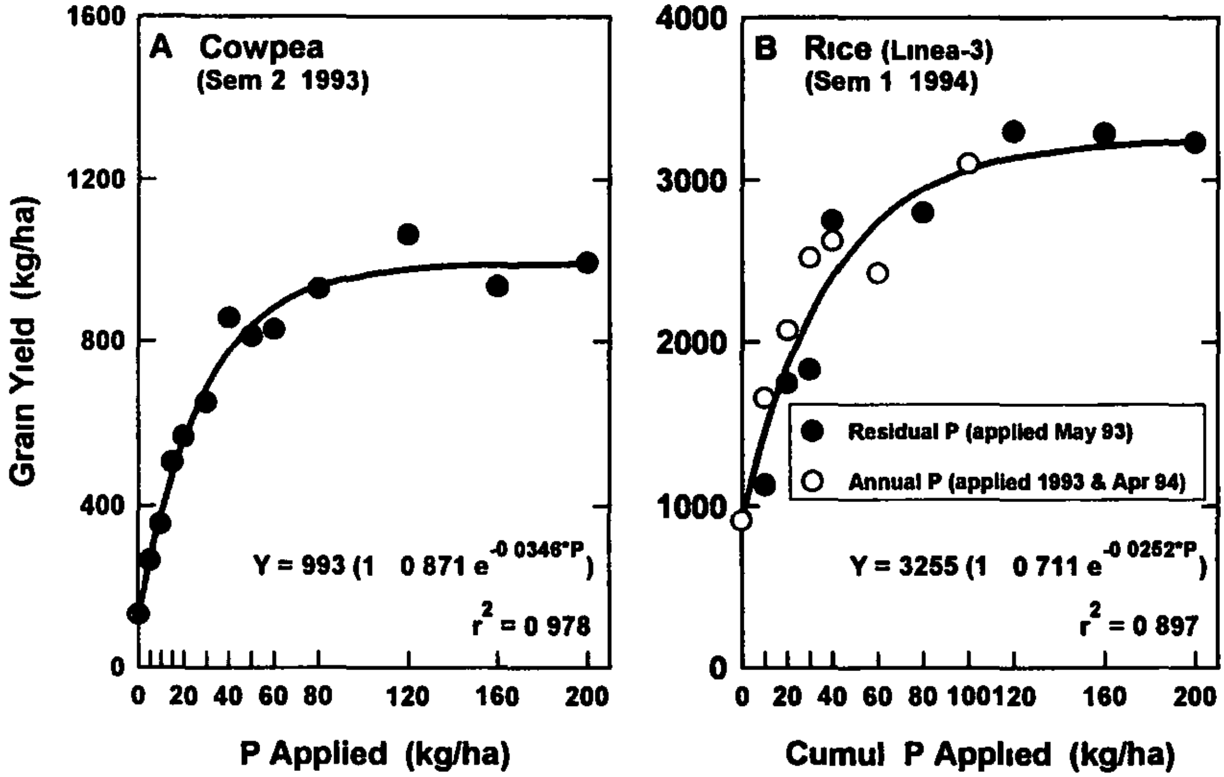


Figure 33 Response of [A] cowpea to residual TSP and [B] rice to residual and re applied TSP on a loamy-clay Oxisol at Matazul Farm

TI02 INTER PROGRAM PROJECT WITH FORAGE PROGRAM NITROGEN FIXATION AND NITROGEN TRANSFER IN FORAGE LEGUMES

Richard J Thomas (TL)

Nitrogen fixation by forage legumes in grass/legume pastures

Rates of nitrogen fixation by forage legumes are normally measured during the first or second year of pasture establishment only and there have been few reports of fixation rates over longer time periods as it is assumed that the legume continues to fix nitrogen at similar rates to those measured during establishment This assumption needs examining however as soil fertility may be declining after the initial fertilizer application given at establishment and there is evidence that decreased soil fertility reduces the % of the legume s N derived from fixation (Tropical Pastures 1987 1991 Report 1991)

Nitrogen fixation in the forage legumes *Arachis pintoi Centrosema acutifolium* and *Stylosanthes capitata* grown in association with the grass *Brachiaria dictyoneura* was subsequently measured for three successive years in the satellite sites to the core experiment in Carimagua (see Biannual Report Savanna Program 1992 93 for details) The amounts of nitrogen fixation per unit legume biomass and % of legume N derived from fixation (%Ndfa) are shown in Table 29 for sandy loam and clay loam soil types and the two levels of initial fertilization used in the core experiment Table 30 shows the data in terms of absolute amounts fixed and % legume in the pasture Initial fertilization had little or no effect on %Ndfa at either site over the three years Similarly the %Ndfa was maintained over time even though soil fertility was supposedly declining The %Ndfa in all three legumes remained at high levels (>80% in general)

Conclusions As reported previously (Biannual Report Savanna Program 1992 93) the main effect of fertility was on legume population (Table 30) and not on fixation per unit biomass and therefore an estimate of the amounts of nitrogen fixed can be made from a measurement of legume biomass in the pasture Thus such estimates can be done very simply in farmer s fields

Non fixing controls In the above experiment the grasses *B dictyoneura Panicum maximum* ecotype KK16 and the native savanna were used as non fixing controls in the ^{15}N isotope dilution technique To check if these were appropriate non fixing controls a glasshouse experiment was done with soil from Intro II (clay loam) to determine the N uptake patterns and N distribution in two grasses non fixing mutants of *Stylosanthes capitata* and the normal N_2 fixing *S capitata* cv Capica The results (Table 31) indicate that in general the amounts of N taken up and its distribution were similar for the non fixing plants but they all differed from N_2 fixing *S capitata*

Conclusions The results imply that caution should be exercised in the estimates of nitrogen fixed as there is no guarantee that fixing and non fixing plants are taking N up from the same soil N pools over time and this may invalidate the isotope dilution technique However the amount of legume N derived from fixation did not differ greatly using any of the non fixing controls in this experiment nor in the field experiments reported previously and in the glasshouse experiment a mean value of 83% ± 2 8% was obtained In addition if the %NDFA is as high as 60% or more then discrepancies in patterns of N uptake will not affect estimates of N_2 fixation greatly The ^{15}N enrichment of the non fixing *S capitata* was similar to the grasses (Table 31) and indicates that it can be used as a valid non fixing control provided N fertilizer is applied to obtain similar growth rates and N accumulation

Table 29 Amounts of N_2 fixed kg N/t legume DM and Ndfa

		A pintoi			*C acutifolium*			*S capitata*		
Site	Fertility	1991	1992	1993	1991	1992	1993	1991	1992	1993
Sandy	Low	18 7			25 3	23 5		27 1	17 9	7 5
		(81 5)			(88 9)	(64 5)		(85 6)	(87 5)	(74 2)
Loam	High	24 4			33 1	20 4	9 2	31 0	17 4	9 3
		(87 1)			(91 7)	(96 3)	(94 5)	(90 2)	(88 0)	(89 3)
Clay	Low	19 7	15 3		29 1	20 3	36 0	21 6	16 6	26 6
		(71 7)	(81 4)		(91 4)	(92 1)	(92 9)	(79 7)	(87 9)	(90 7)
Loam	High	22 8	17 9	23 3	29 1	25 5	(38 0)	22 4	16 0	28 0
		(85 6)	(68 3)	(81 7)	(92 9)	(95 4)	(95 9)	(89 1)	(92 2)	(89 0)

Number in brackets are % Ndfa

Table 30 Amounts of N_2 fixed over 12 weeks kg N/ha and % legume content in pasture

		A pintoi			*C acutifolium*			*S capitata*		
Site	Fertility	1991	1992	1993	1991	1992	1993	1991	1992	1993
Sandy	Low		0 8		1 7	0 3		21 0	4 4	0 3
			(4 0)		(5 0)	(1 4)		(46 3)	(6 3)	(1 4)
Loam	High		7 4		2 5	0 8	0 2	40 0	2 2	0 4
			(17 7)		(4 5)	(2 3)	(0 8)	(44 2)	(16 5)	(1 0)
Clay	Low		0 9		3 5	2 4	0 50	14 8	4 7	0 8
			(1 9)		(4 6)	(6 6)	(1 4)	(27 0)	(24 0)	(2 4)
Loam	High		6 8	0 70	5 2	4 6	(2 6)	31 0	6 0	2 6
			(10 0)	(2 4)	(5 4)	(9 4)	(6 2)	(32 3)	(21 6)	(7 2)

Number in brackets are % legume contents in the pastures

Table 31 Comparison of non fixing controls in the estimate of N_2 fixation by *S capitata*

Species	DM (g/plant)	% biomass above ground parts	Total N mg/plant	% N in above ground parts	% atom ^{15}N excess
S capitata fixing	1 75 ab	70 5 a	41 4 a	75 7 a	0 048 a
S capitata non fixing	0 75 c	69 6 a	7 0 b	57 4 b	0 312 b
P maximum	1 32 b	65 2 a	6 9 b	54 2 b	0 266 b
B dictyoneura	1 93 a	53 3 b	8 6 b	56 8 b	0 275 b

Glasshouse grown plants harvested 30 days after planting Means of 5 repetitions
Number followed by similar letters in each column do not differ significantly ($P < 0\ 05$)

CHAPTER VI

INTERPROGRAM PROJECT TI 01 PROTOTYPE SYSTEMS FOR ECOLOGICALLY SOUND INTENSIFICATION OF PRODUCTION IN THE HILLSIDES

Prepared by *José Ignacio Sanz*

Collaborating CIAT Scientists (in alphabetical order)

E Amézquita (TL) J Ashby (HS) R Best (Cassava) D K Friesen (IFDC/TL) S Fujisaka (LM SRG) A Gijsman (TL) C Iglesias (Cassava) B Knapp (HS) J Kornegay (Bean) C Lascano (TF) B Maass (TF) K Muller (Cassava HS) J I Sanz (Project Leader) J Smith (TL) R Thomas (TL) C A Quiroz (HS) A Meléndez (HS)

A Introduction Justification

The project aims to contribute to the Program s goal about the development of knowledge on how to combine conservation and production technologies with the aim of regenerating the natural resource base while being economically viable to farmers The purpose of the project is to develop sustainable agrosilvopastoral systems that improve soil quality water management and efficiency and productivity of labor

After consulting with researchers and farmers involved with hillside activities as well as a broad local and international literature search it is clear that most of the existing hillsides research consists of site or single problem specific experimental work (eg Magolis et al 1991 Garcia and Marcano 1990 Raros 1985) or socioeconomic studies (eg Browman 1984) normally not followed on to solve the encountered needs and even misconceived strategies as reported also by Browman 1987 There is a general deficiency on attempts to derive principles with strategic validity either at the site level as well as at a more coordinated international macrolevel eg Andean hillsides within a range of predefined characteristics

It is important for CIAT s Hillsides Program to fill the existing gap at an international level We need to bring in and take out the generated data and experience taking place in different parts of the Andean region This would make possible extrapolation across similar environments aiming for a large scale impact

More specifically research on integrated crop livestock systems including studies on nutrient cycling and nutrient use efficiency is weak in the region Also research involving trees is almost all concentrated on agroforestry but not on agropastoral or agrosilvopastoral systems

The project aims to increase the use of perennial plants (grass and legume forages as well as trees) in cropping systems and in varying landscapes In doing so it attempts to develop principles on multifarm systems that can improve the efficiency of the use of the land both in time and space while increasing the ability to preserve the environment

The project in the first few years is starting in the watershed of the Río Ovejas in Cauca Colombia Representativity of the experimental sites is being chosen with the help of national institutions local organizations as well as GIS and secondary information on soils climate vegetation actual land use etc available for the area Extrapolability to other hillside areas in Latin America of the derived principles from this project in its first few years is expected also with the help of similar institutions GIS as well as modelling tools

The Río Ovejas watershed covers 106 000 hectares ranging between 1100 and 3000 m a s l with 67% of farmers with less than 3 ha of land The population is 85 000 with 41% illiterate The natural forest vegetation cover is on average 4% for the watershed

With the few figures quoted above it can be seen that the Río Ovejas watershed represents the typical hillside situation for Latin America today high density of a population with limited formal education rapid depletion of forests soil losses associated with monocropping very few technological and policy alternatives The consequences of this erosion extend beyond the watershed affecting downstream water quality and producing sedimentation of rivers and dams At the same time low incomes imply little access to inputs leading to depletion of the soil for food production Thus typifying the cycle of poverty degradation further poverty

Many organizations both government and non government have been trying to implement sustainable land use practices in our study area and in general in the Latin American Hillsides Unfortunately successful widespread adoption of studied practices is not common due to several reasons such as lack of vigorous research on the ecological processes that the induced practices aim to sustain a very fragmented process of trial and error focused on productivity and ignoring long term development and conservation needs and weak and unsustained research capability

B Problem solving strategy and expected outputs

The group of collaborating CIAT scientists in the project through a process of Planning by Objectives identified a set of major problems to be dealt with by our research agenda These problems are

1 Deterioration of soil quality soil erosion fertility decrease decreased nutrient regeneration (shorter fallows)

2 Unrealized production potential of existing farming systems lack of complementarily of farm activities increased pesticide use poor linkage between farming systems and markets

3 Poor water management limited irrigation for small farmers water pollution limitation of water management due to topography

4 Low labor productivity

5 Poor information

6 Deficient infrastructure

Based on the above problems and in order to comply with the stated purpose of the project the expected outputs are

1 Sustainable agrosilvopastoral systems
2 Stable or improved soil quality

3 Improved water management
4 Improved labor productivity and efficiency

In this section only the first three outputs will be dealt with and the socioeconomic aspects specifically market opportunities and soil erosion are dealt with separately in the Interprogram Project in Hillsides Subproject market opportunities linked to erosion control practices a key to adoption?

Recent surveys carried out by the Program show that important monocrops in the area in order of decreasing area are cassava (16 18 months cycle labor intensive) coffee sugar cane beans (becoming more important) maize tomato sisal plantain fruits Intercropping is common in the area eg cassava beans and cassava maize beans in the low altitude cassava maize and plantain coffee sisal in mid altitude

The strategy consists of covering the range from short cycle shallow rooted monocrops to deep rooted perennial and more diverse agrosilvopastoral systems It will include existing as well as proposed systems identified either by farmers national institutions and/or CIAT s scientists

The site selection for the initial phase was at 1500 m in order to fit in the range of 1400 m a s l to about 1800 m a s l to ensure adaptation of CIAT s germplasm

The site selection in terms of representativity within the watershed and the extrapolability outside the watershed of the encountered principles of this research was discussed in p l above

In the initial phase the experiments are simple and as large as possible including areas for cattle grazing in some instances They are planned for long term evaluation and in this way (large and simple) they will allow for future additions and modifications along as progress is made in the evaluations and contributions from the collaborators (national institutions farmers and CIAT scientists) come into the process

C Selected systems and hypotheses

The crops and pastures are viewed within the systems as plant types

beans short term shallow rooted
maize medium term medium rooted
cassava long term deep rooted
pastures perennial deep rooted herbaceous
trees perennial deep rooted woody

In the selected farm sites the following systems are being evaluated

1 Monocrops cassava maize beans

2 Maize + legumes cocktail (green manure or forage) in two contrasting fallows (cropped land and 2 years old fallow)

3 Maize + *Brachiaria dictyoneura* + legumes cocktail (for grazing) (to compare with 1 above and 4 and 8 below)

4 Naturalized grass (*Melinis minutiflora*) for grazing (to compare with 3 above and 8 below)

5 Cassava + legumes cocktail (green manure or forage) in two contrasting fallows (as in 2 above)

6 Triple crop association beans + cassava + maize

7 Barriers and field(s) perimeter(s) with grasses grasses + legumes and grasses + legumes + trees

8 Cut and carry species on steep slopes grasses and legumes trees (to compare with 3 and 4 above)

9 Uncropped plots subdivided in bare and mulch cover for soil physics studies

Systems 2 and 5 above are in two sites with varying conditions and all systems with three replications except systems 3 and 4 which are respectively 1 and 0 7 ha for grazing

System 1 is traditional monocropping without conservation practices and System 4 is for traditional grazing of naturalized pastures

Systems 2 and 5 are the same as System 1 but they already include a cover crop (legumes) for soil protection/fertility enhancement

System 6 includes the three crops from System 1 but all together in the field aiming for continuity of production/income

System 3 has only one season with a crop and is continued without further tillage under improved grass/legumes cover for grazing

System 8 on steep slopes aims to have perennial species for cut and carry without further tillage after the initial one

System 7 aims soil protection while being productive

In these systems there is a gradient from shallow rooted short cycle systems to perennial both herbaceous and woody deep rooted systems System 9 uncropped plots with bare and mulch covered plots represent the two extremes of the gradient

The general hypotheses for the project are through perennial deep rooted systems it is possible to

1 Improve quantity and quality of soil organic matter

2 Hold soil in place against erosion

3 Improve microbial activity

4 Stabilize/increase soil fertility

5 Have less variability more security of income cash flow

The germplasm has so far been selected as follows

Crops the most common in the area and in CIAT and CIMMYT commodities cassava (Algodona) beans (Caucayá) maize (Sikuani 1)

Grasses and legumes the outstanding materials in both CIAT s trials and farmers evaluation Grasses *Brachiaria dictyoneura* *Pennisetum purpureum* (elefante enano) *Axonopus scoparius* (imperial 60) and *Melinis minutiflora* Legumes *Centrosema acutifolium* *Arachis pintoi* *Stylosanthes capitata* *Chamaecrista rotundifolia* and *Desmodium macrocarpum*

Barriers German project results and farmers opinion Elefante enano Imperial 60 sugar cane pineapple (local variety) and several species of legume trees

Trees CIAT s farmers and CVC s recommendations until now There is need to keep looking for adapted useful species and systems in this area of research *Calliandra calothyrsus* CIPAV 2 *Cajanus cajan* CIAT 18700 *Codaryocalix gyroides* CIAT 3001 and 23748 *Cratylia argentea* CIAT 18516 *Sesbania sesban* CIAT 21250 *Indigofera* sp *Leucaena leucocephala* CIAT 17474 *Desmodium velutinum* CIAT 134218 *Erythrina edulis* *Dendrolobium* sp *Desmodium cajanifolium* CIAT 3124 *Tadehagi triquetrum* CIAT 13276 *Leucaena diversifolia*

D Satellite experiments

These are for testing a number of lines of the selected crops in order to evaluate their behavior in comparison to the varieties used in the systems trials 1) Beans 11 lines (3 reps) 2) Cassava 5 lines (4 reps) 3) Rice 2 lines (1 rep) 4) Legume trees several species (3 reps)

E The way ahead

It is expected that the trials themselves will serve the purpose of demonstration trials in farmers fields where our collaborating institutions and farmers have an open access for training activities In the future if resources allow the work should scale up to other areas within Colombia and other countries in the region with similar hillside ecosystems and start networking and sharing experiences as it is already happening with our work in the savannas The purpose would be to standardize methodologies identify common treatments to facilitate comparisons across sites to benefit from the experiences available in the region and to exchange information with the various participants

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Apart from the input by the various collaborators some existing documents were quoted or new ones were prepared for the elaboration of this Project

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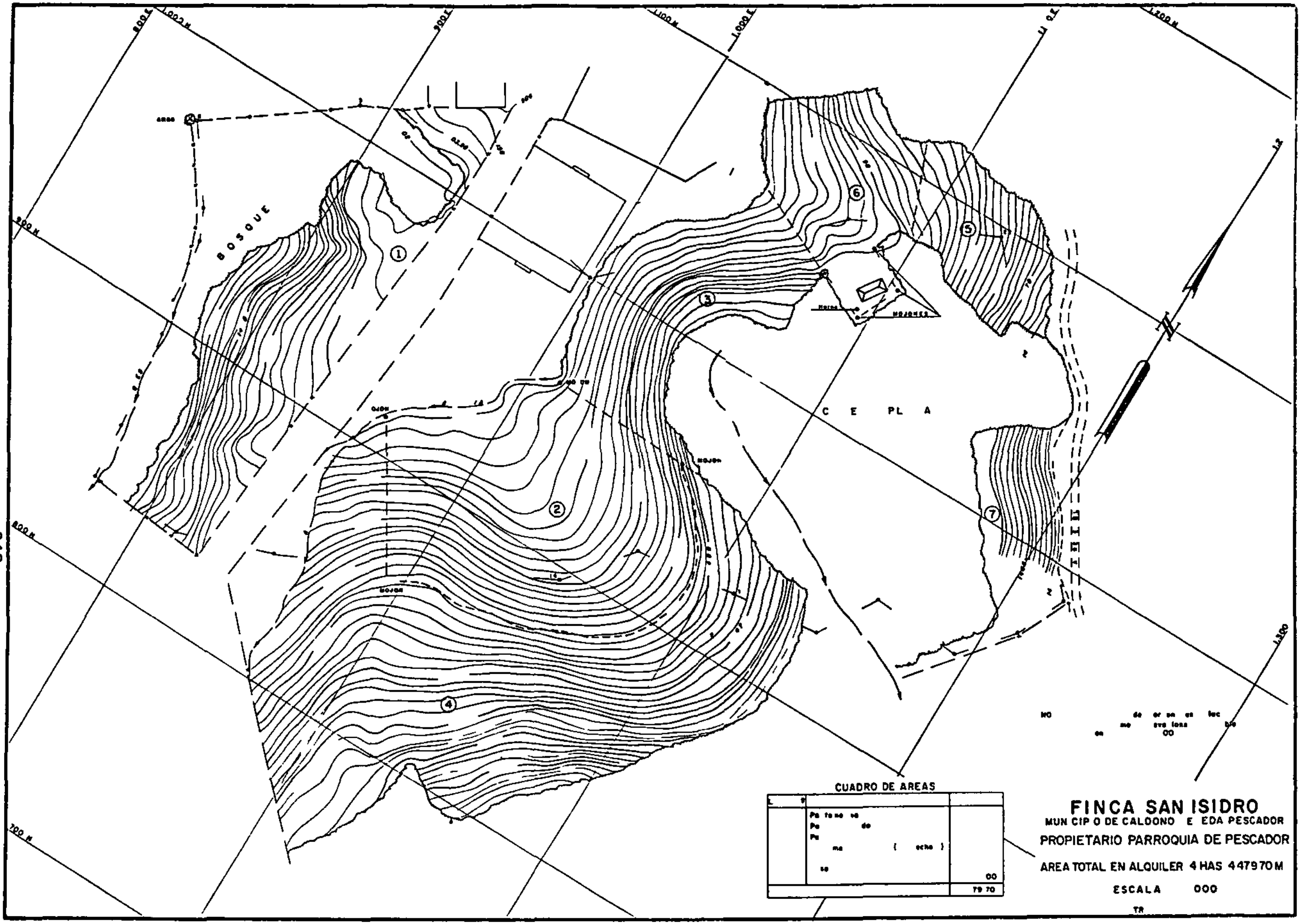

BOSQUE
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Interprogram Project in Hillsides TI 01 subproject Market opportunities linked to erosion control practices a key to adoption? *Joyotee Smith (TL)*

Introduction

Justification in the regional context

A number of authors have linked the social and resource degradation problems of tropical America to imbalances between rural and urban development policies inequality in access to resources and the promotion of capital intensive modes of production both in agriculture and industry (Gutman 1988 Leonard 1987) Expansion of agriculture in the fragile ecosystems of the midaltitude hillsides was largely a result of the appropriation of the best lands by the conquistadors during the colonial period and their incorporation into large farms devoted to cattle ranching or the cultivation of commercial crops (Carter 1991) As the indigenous population increased restrictions in he access to land led to population movements to the hillsides which are where today most of the poor farmers reside Maintenance of the natural resource base in the hillsides is thus of vital importance not only to ensure the future livelihood of resource poor farmers but also to prevent their future migration to urban centers thus augmenting the social problems which are endemic among resource poor migrants in urban areas

Justification in the context of the program

The goal of the Hillsides Program is to develop knowledge about how to combine conservation and production technologies in ways that sustain and regenerate the natural resource base and are also economically viable and acceptable to farmers The program has identified soil erosion as one of the most pressing resource management problems

The literature on erosion control technologies in tropical countries is however characterized by one dominant theme disappointing levels of adoption (Laing and Ashby 1992 Kaimowitz 1992) The literature also shows that given the farmer s circumstances soil depletion in many cases is rational from the farmers point of view (Ashby 1985 Anderson and Thampapillai 1990) As soil degenerates over time yield and income losses build up At early stages of soil depletion the net returns without soil conservation exceed the net returns with conservation Over time as soil degenerates further the gap declines until eventually net returns with conservation are higher than those without Adoption is unlikely to occur until this point which one study calculates to be at least 40 to 60 years after degeneration begins depending on the discount rate used (Seitz and others 1979) Thus there is a conflict between the farmers economic logic and ecological considerations (Gutman 1988) The literature also points out that while farmers consider the monetary benefits of erosion control such as yield increases they are unlikely to consider non monetary benefits such as soil resilience or downstream benefits which accrue to others Thus the extent to which soil conservation practices are voluntarily adopted by farmers will be suboptimal from society s point of view (Izac 1994)

The problems with adoption raised above imply that farmers will have to be offered incentives to induce the timely adoption of soil conservation practices Incentives have commonly taken the form of subsidies or regulations The former however is costly and in many cases induces distortions in other sectors of the economy The latter is extremely difficult to implement The research reported here explores a different type of incentive The objective is to identify income earning opportunities linked to soil conservation practices Adoption is expected to occur because of the opportunity to increase income with soil conservation occurring as a byproduct This approach derives support from the fact that in the few cases of successful adoption that have occurred soil conservation practices permitted the introduction of high value crops or supported the introduction of livestock or generated income by being associated with value added processes (Tiffen 1993 Nimlos and Savage 1991) Linking the market opportunity to conservation practices is however vital as the literature is replete with cases where the introduction of income generating opportunities without any links to conservation have exacerbated resource degradation (Thrupp 1993)

The research reported here is part of a larger project which seeks to develop prototype systems for ecologically sound intensification of production in the Hillsides From the ecological point of view the strategy is to achieve a transition from short cycle shallow rooted monocrops to deep rooted perennial more diverse agrosilvopastoral systems The project includes sociological studies of farmer typologies (Helle) basic studies on the physical aspects of soil erosion (Jesus Castillo) studies of the relationship between soil erosion and productivity of major crops in the area (Felicitas) the development of technologies for using barriers for erosion control (Karl Muller) a consortium of various types of institutions including NGOs who will be principally responsible for implementation of technological and institutional findings The research reported here complements this work by

a) Investigating the market potential of materials being used in the barriers currently under development
b) Identifying alternative market opportunities whose potential for erosion control and compatibility with the strategy of the project will be investigated
c) Identifying institutional arrangements required to enable farmers to exploit market opportunities
d) Incorporating results of farmer typologies in the analysis of the adoptability of alternative erosion control technologies

Problem Solving Strategy

The basic hypothesis is that technology and institutional linkages are key factors in providing resource poor farmers with market opportunities linked to conservation practices

Some of the options currently being considered by biophysical scientists include perennial and annual forages for their potential as feed for dairy cattle cereals such as millet to be used as poultry feed for egg production perennial barriers such as citronella with potential for industrial use and vetiver grass with very minimal economic value The current project will help biophysical scientists narrow down options for inclusion in prototype systems At the same time it will provide ideas for new options by identifying new market opportunities whose erosion control potential will be investigated by biophysical scientists Their results will in turn feed into the ex ante economic evaluation of potential technologies

The research comprises the following steps

a) Identification of market opportunities
b) Evaluation of erosion control potential of identified market opportunities

c) Identification of institutional mechanisms required to support market opportunities with erosion control potential
d) Ex ante evaluation of adoptability
e) Implementation of institutional mechanisms on a pilot basis
f) Ex post evaluation
g) Extrapolation to other sites

a) Identification of market opportunities (*Carlos Ostertag*)

This will help bio physical scientists narrow down options for inclusion in prototype systems

The search for market opportunities will be based on Ansoff s (1957) framework for strategies to achieve growth in markets

	Current Products	New Products
Current Markets	Market penetration	Product development
New Markets	Market development	Diversification

Market penetration uses marketing tools such as price reduction or quality improvement to achieve increases in market share in current markets Returns and risk are usually low

Market development identifies new users (such as institutional users) or new geographic areas (such as export markets) for selling the same products as before Returns and riskiness are usually moderate

Product development offers new or modified products such as organically produced products in current markets This is also a strategy of moderate returns and riskiness

Diversification offers new products in new markets eg exporting flowers These are usually characterized as high risk high returns strategies

A demand driven approach will be taken with the identification of opportunities being based on the needs and wants of target markets such as supermarkets manufacturers of processed foods intermediaries etc

b) Erosion control potential of identified market opportunities

This activity will be carried out mainly by the biophysical scientists in the project (Karl Muller J I Sanz Jesus Castillo) and is expected to suggest new options which prior to the identification of their market value may have been rejected by biophysical scientists on the basis of their erosion control abilities

c) Identification of institutional mechanisms to support market opportunities *Carlos Ostertag (HS)*

This will be based on an analysis comparing current and historical marketing arrangements with potential new institutional arrangements proposed by target purchasers of farm products The analysis will assume that production costs include both transformation costs and transactions costs such as search costs information costs and enforcement costs (North 1990) Based on Coase s (1960) proposition that the efficient competitive equilibrium of neoclassical economics obtains only when transactions costs are zero and that institutions are mechanisms for reducing transactions costs the analysis will identify the most important transactions costs in current institutional arrangements and identify new institutional arrangements which minimize these costs The conceptual framework of Kohls and Ulh (1992) will be used to classify current historical and potential new arrangements Three types of marketing functions will be considered (a) exchange functions or activities involved in the transfer of title of goods such as buying and selling (b) Physical functions ie activities involving handling moving storing and physically transforming the commodity (c) facilitating functions or activities involved in lowering the transactions costs of the other two functions Examples are Standardization of goods which reduces information costs and insurance which reduces the cost of uncertainty Whenever possible quantitative measures of the extent to which each institutional arrangement lowers transactions costs will be obtained Qualitative assessments will be used where quantification is problematic

d) Ex ante evaluation of adoptability *Jairo Castano (HS)*

This will include two activities

(i) A study of the extent to which conservation practices have been adopted

(ii) the estimation of a multiple goal linear programming model (McGregor and Dent 1993 Cocklin et al 1998 Ignizio 1985) This is a normative model which can be used to identify potential conflicts between multiple goals eg farmer s goals which could lead to adoption vs minimization of soil erosion The analysis indicates to what extent underachievement of one goal is required in order to achieve satisfaction of another For example vetiver grass barriers may achieve the soil conservation goal but may result in substantial underachievement of farmers goals and therefore have little success of adoption without subsidies which would help farmers achieve their goals An alternative barrier such as a perennial forage such as elephant grass may underachieve both the soil conservation goal and farmer goals without institutional arrangements related to milk marketing Appropriate institutional arrangements may however enable it to meet farmer goals and thus lead to voluntary adoption Thus tradeoffs between the goals become evident Thus the model is a tool to aid decision makers involved in rural development

The specification of farmer goals will be based on Helle s research on farmer typologies Ecological goals and ecological impacts of technological alternatives will be provided by Muller Sanz and Castillo Only on site effects will be considered Carlos Ostertag s work will be used to identify new options for inclusion in the model and to simulate the impact of institutional marketing arrangements

e) Implementation of institutional arrangements on a pilot basis

This will be the responsibility of consortium members particularly the NGOs

f) Expost evaluation

This will consist of a conventional adoption study

g) Extrapolation

Given the heterogeneity of hillsides in tropical America the objective of a study such as this in a particular site is to derive principles about how to proceed with a similar problem in other sites Criteria will be developed to characterize

1) Institutional arrangements This will be done by characterizing each institution according to the types of transactions costs it reduces
2) soil conservation technologies according to resources required for adoption and according to effectiveness in controlling erosion
3) farmers socioeconomic and biophysical environment in terms of transactions costs resource availability and the extent of soil depletion

An expert system will then be developed which matches characteristics of the farmers environment to characteristics of technologies and institutions

The innovativeness of the research lies in the following

1) The focus of the CG system so far has been on developing biophysical technologies with socioeconomic constraints taken as given The objective of this research is to overcome a socioeconomic constraint lack of market opportunities by introducing a social technology viz institutional marketing arrangements
2) Incentives for adoption of conservation technologies have usually been in the form of subsidies or regulations the difficulties associated with which are widely known This study tries to develop a method for voluntarily inducing adoption for income generation reasons with conservation occurring as a byproduct
3) The emphasis on transactions costs is in line with new trends in economics research oriented towards relaxing the restrictive assumptions of neoclassical economics (see Pacer 1993)
4) The use of multiple goal programming to examine tradeoffs between income and resource conservation is rare in tropical agriculture

Progress Report

a) Qualitative interviews on 7 historical institutional arrangements have been completed The results show that institutions are unable to reduce the transactions costs of selling output as compared to intermediaries Institutions have been more successful in lowering information costs related to quality requirements of target markets and access to improved technologies

b) Informal interviews with a small sample of farmers shows that dairying is regarded as highly profitable but very capital intensive One option may be institutional marketing arrangements for milk or milk products with better off farmers who would purchase forage from poorer farmers A similar arrangement may be possible in the case of panela production with poorer farmers providing sugarcane for processing by better off farmers Technological assistance via institutional arrangements will be required as farmers consider upland cane production unprofitable Current Panela processing technologies are also regarded as only marginally profitable Much interest in horticulture was also revealed

c) Past institutional experiences highlighted the cyclical nature of cash crop successes This indicates the need for a diversified portfolio Under the aperture it may also be less risky to focus on products which are not tradeable because of bulk or perishability Examples are fresh milk or forages

d) Interviews carried out with field staff of the H/S program resulted in a preliminary farmer typology indigenous inhabitants traditional Caucanos progressive caucanos and nariñenses Objectives attitude to risk time horizon and attitude to soil conservation were ascertained Information was also obtained on seasonality in labor requirements cash and food availability land tenure and availability of credit changes in crop composition The dominant form of output disposal is to intermediaries

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IFDC International Fertilizer Development Center Muscle Shoals AL **United States**

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INA PG Institut National Agronomique de Paris Grignon **France**

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MARNR Ministerio del Ambiente y de los Recursos Naturales Renovables Caracas **Venezuela**

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