CENTRO INTERNACIONAL DE AGRICULTURA TROPICAL, CIAT

TROPICAL FORAGES AND SAVANNAS PROGRAMS

BRIEEFING NOTES FOR VISIT TO CORE EXPERIMENT

CARIMAGUA, 18 AUGUST 1993

CALI, COLOMBIA, SUR AMERICA

BRIEFING NOTES FOR VISIT TO CORE EXPERIMENT
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SECTIONS — All members of the Pasture Development Unit

PERSONNEL — M Ayarza C Lascano M J Fisher T Nada
I M Rao G Rippstein R Thomas

RATIONALE — In order to investigate aspects of maintenance fertilizer nutrient cycling pasture stability animal performance and their interactions with contrasting pasture associations and soils of differing textures a comprehensive experiment has been established at the CNI-Carimagua field station

The present project is the end-product of many years of work by the TPP on germplasm introduction and evaluation Hitherto we have been measuring pasture performance by means of the liveweight gains of cattle but this has largely not addressed adequately the important role of nutrient cycling and soil improvement With well-adapted species that are deep-rooted and showing evidence of stability in the longer term it now possible to enter the ultimate stage to seek understanding of the system The experiment is designed to provide information on the interaction between

- pasture association
- soil texture
- level of fertility
- stocking rate

The experiment will provide the basis to understand the pasture complex that is the relations between soil/plant/animal and to measure recycling of nutrients under a sufficiently wide range of treatments that will enable the development of understanding of nutrient cycling in acid poor soils and where adapted plants are involved The project will enable the acquisition of knowledge of the principles underlying the pasture technology as well as the development of novel methodologies For example the extraction methods currently used to obtain measures of available nutrients (e g P and K) are in sensitive and probably inappropriate insofar as they probably do not mimic the extraction mechanisms of the plants

It is also necessary to stress that the experiment also includes pastures established at higher levels of input fertilizers on the one hand and with maintenance fertilizer on the other

The associations represented are in some ways compromises between the best germplasm and the greater certainty of successful performance For example Brachiaria dictyoneura was chosen as a common grass in both the sandy and the clayey soil sites because of the danger that leaf-cutter ants might destroy a pasture of Andropogon gayanus on the sandy soil to which the latter is putatively better adapted This decision was taken despite the greater susceptibility of B dictyoneura to attacks by spittlebug

The core experiment will serve as the focal point for the collaborative studies of the Pasture Development Unit (PDU) described in greater detail in the following pages Reference to the program for the forthcoming workshop will show that the International visitors will be invited to visit Carimagua on Monday 10 September to familiarize themselves with the llanos environmnet and the experiment in the field

EXPERIMENTAL DESIGN

SITES

Two -

- heavy soil (ca 10% sand)
- light soil (ca 50% sand)

ASSOCIATIONS * FERTILIZERS

Four -

- grass alone with pasture fertilizer
  i e initial + no maintenance (PF)
- grass + legume with pasture fertilizer
  i e initial + no maintenance (PF)
- grass + legume with crop fertilizer but no
  maintenance (CF)
- grass + legume + maintenance fertilizer (MF)

STOCKING RATES

Three -

- low (L)
- medium (M)
- high (H)

REPLICATES

Two of the treatments at each site

STRUCTURE

Incomplete factorial
The four paddocks of each treatment blocked
by pairs

Grass (PF)	Grass/legume (PF) A	Grass/legume (PF) B	Grass/legume (CF) A	Grass/legume (CF) B*	Grass/legume (MF) A	Grass/legume (MF) B*
-	L	L	-	-	-	
M	M	M	M	M	M	M
-	H	H	-	-	-	-

* only for heavy soil

NUMBER OF PLOTS

9 * 2 = 18 (sandy soil)
11 * 2 = 22 (clayey soil)

GRASSES Brachiaria dictyoneura (both sites)

LEGUMES

Sandy soil

A Centrosema acutifolium cv Vichada
B Stylosanthes capitata cv Capica

Clayey soil

A Centrosema acutifolium cv Vichada
B Arachis pintoi CIAT 17347

STOCKING RATES (Animals/ha)

Sandy soil

Grass (PF)	Grass/legume (PF) A	Grass/legume (PF) B	Grass/legume (CF) A	Grass/legume (CF) B	Grass/legume (MF) A	Grass/legume (MF) B
-	1 0	1 0	-	-	-	
1 5	1 5	1 5	1 5	-	1 5	-
-	2 0	2 0	-	-	-	-

Clayey soil

Grass (PF)	Grass/legume (PF) A	Grass/legume (PF) B	Grass/legume (CF) A	Grass/legume (CF) B	Grass/legume (MF) A	Grass/legume (MF) B
-	1 5	1 5	-	-	-	-
2 0	2 0	2 5	2 0	2 5	2 0	2 5
-	2 5	3 0	-	-	-	-

INTRODUCTION

The savannas of the lowland tropics of Latin America have large areas of infertile, acid soils with native vegetation of low quality and productivity These areas have consequently been used traditionally for extensive cattle ranching, and more recently in cropping in certain parts of the cerrados of Brazil and the llanos of Venezuela Increasing pressure from population growth, poverty and associated degradation of the environment requires increased production of meat, milk and crops in these lands in sustainable systems These increases must come from legume-based pasture systems where the use of large amounts of fertilizers is generally not a feasible nor a desirable option

The Tropical Pastures Program (TPP) of CIAT has developed low-input technologies to improve productivity by introducing new grass and legume germplasm that are well-adapted to the poor, acid soils In these systems the legume plays a key role in pasture improvement by its ability to provide a source of nitrogen by means of fixing atmospheric nitrogen, by stimulating the cycling of other nutrients and by improving pasture quality for grazing ruminants

Although spectacular increases in animal productivity have been obtained using legume-based pastures compared with the native vegetation or grass alone pastures, we do not know how sustainable these systems are, how they can be managed to maintain an adequate legume content or to what extent the introduction of new grass/legume species can improve soil fertility for continued pastoralism or agropastoralism Moreover, it is necessary to formulate pasture associations between the new legumes and grasses, and to design systems of management appropriate to ensure high levels of productivity, stable in the longer term

Pastures are complex systems, much more so than crops in general because the time scale involved is much longer, there is far less scope to manipulate the conditions for plant growth, several different plant species are involved, usually with contrasting physiologies, and moreover the grazing animal exerts such a profound influence

Legume-based tropical pastures have a very important role to play in the recuperation of lands that have been degraded by use of imprudent cropping or animal production systems Therefore, it is important to understand nutrient cycling, and the accretion of organic matter under grazed legume-grass pastures Tropical pasture systems are probably more difficult to manage than their temperate counterparts, largely because the component grasses and legumes have fundamentally different physiologies

In this situation, traditional empirical research requires large resources and can make only slow progress, which is usually achieved without any clear understanding of the processes critical to the functioning of the system However, considerable progress has been made with some temperate pastures by synthesizing knowledge of the physiology of the plants that comprise the pasture, how they react to the various factors in the environment that limit plant growth, and the influence of the grazing animal, both as a consumer of the herbage, and a key component in the cycling of nutrients The synthesis takes the form of a mathematical model in which the responses of the various parts of the system are described by a series of equations, which behave in such a way as to mimic the behaviour of a pasture under grazing Models such as this not only give qualitative information about the relationships between the various components and management strategies, but also serve to identify the key processes in the system

To improve our understanding and ability to define management rules for pastoralism and/or agropastoralism, an integrated multidisciplinary approach is required The TPP has assembled such a group as the Pasture Development Unit (PDU) with the objective of obtaining understanding of the relationships between

- soil factors and germplasm
- nitrogen fixation and recycling
- nutrient recycling and maintenance fertilizer
- legume/grass compatibility and competition
- grazing selectivity
- maintenance and its influence on plant productivity, persistence and competition, nutrient cycling and animal production

As there is no possibility of this small unit measuring and quantifying all aspects of the complex legume-grass system under grazing, a modelling approach is being adopted, to use the data from existing work and from a long collaborative field experiment at the CNI-Carimagua field station Data will be collected concurrently with the development of a model of a tropical pasture with the collaboration of Dr J H M Thornley of the Institute of Terrestrial Ecology in the United Kingdom This integrated approach should allow the effective modelling of some contrasting acid-soil tolerant legume/grass associations grown on soils of contrasting textures

It is obvious that legume/grass pastures for the lowland tropics are complex systems, and as such are difficult to model, but the benefits that may accrue from modelling are correspondingly great, as the need to integrate and to examine the effects of this complexity is more pressing Moreover, the use of a model allows the researchers involved to identify and to concentrate on key processes and to combine their results and knowledge in the model

No model exists that describes the relations between the components of a tropical pasture Nevertheless, given the limited resources available, the only way to make progress will be to use a modelling approach Dr J H M Thornley, the mathematical modeller who created the Hurley pasture model, has considered the project, and has indicated a willingness to contribute to the project by developing a model of tropical legume/grass pastures under grazing

The objective of the workshop is to collate recent advances in relevant disciplines, particularly methodological advances with the help of invited experts and to solicit these experts' views on the PDU experiment initiated at Carimagua, and the proposals of the Unit

SECTIONS All members of the Pasture Development Unit

PERSONNEL M Ayarza, C Lascano, M J Fisher, Y Nada, I M Rao, G Rippstein, R Thomas

RATIONALE In order to investigate aspects of maintenance fertilizer, nutrient cycling, pasture stability, animal performance, and their interactions with contrasting pasture associations and soils of differing textures, a comprehensive experiment has been established at the CNI-Carimagua field station

The associations represented are in some ways compromises between the "best" germplasm, and the greater certainty of successful performance For example, Brachiaria dictyoneura was chosen as a common grass in both the sandy and the clayey site, because of the danger that leaf-cutter ants might destroy a pasture of Andropogon gayanus on the sandy soil to which the latter is putatively better adapted and despite the greater susceptibility of B dictyoneura to attacks by spittle bug

The core experiment will serve as the focal point for the collaborative studies of the Pasture Development Unit (PDU) described in greater detail in the following pages Reference to the program for the workshop will show that the International visitors will be invited to visit Carimagua on Monday, 10 September, to familiarise themselves with the llanos environmnet and the experiment in the field

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  maintenance (CF)
- grass + legume + maintenance fertilizer (MF)

STOCKING RATES

Three -
- low (L)
- medium (M)
- high (H)

REPLICATES

Two, of the treatments at each site

STRUCTURE

Incomplete factorial
The four paddocks of each treatment blocked by pairs

Grass (PF)	Grass/legume (PF)		Grass/legume (CF)		Grass/legume (MF)	
	A	B	A	B*	A	B*
-	L	L	-	-	-	-
M	M	M	M	M	M	M
-	H	H	-	-	-	-

* only for heavy soil

NUMBER OF PLOTS
9 * 2 = 18 (sandy soil)
11 * 2 = 22 (clayey soil)

GRASSES *Brachiaria dictyoneura* (both sites)

LEGUMES

Sandy soil
A *Centrosema acutifolium* cv Vichada
B *Stylosanthes capitata* cv Capica

Clayey soil
A *Centrosema acutifolium* cv Vichada
B *Arachis pintoi* CIAT 17347

STOCKING RATES (Animals/ha)

Sandy soil

Grass (PF)	Grass/legume (PF)		Grass/legume (CF)		Grass/legume (MF)	
	A	B	A	B	A	B
-	1 0	1 0	-	-	-	-
1 5	1 5	1 5	1 5	-	1 5	-
-	2 0	2 0	-	-	-	-

Clayey soil

Grass (PF)	Grass/legume (PF) A	Grass/legume (PF) B	Grass/legume (CF) A	Grass/legume (CF) B	Grass/legume (MF) A	Grass/legume (MF) B
–	15	15	–	–	–	–
20	20	25	20	25	20	25
–	25	30	–	–	–	–

SECTIONS N_2 Fixation/Recycling, Soil-Plant Relationships and Nutrient Cycling

PERSONNEL R Thomas, I Rao, and M Ayarza

RATIONALE The productivity of tropical pastures is frequently limited by the low availability of soil nutrients especially P and N (Sánchez, 1987) The use of fertilizer to maintain or increase the productivity of pastures is generally economically prohibitive in the savanna lands of Latin America Therefore, the introduction of a forage legume into tropical pastures is considered to be essential (Toledo, 1985) The input of biologically fixed N from legumes is thought to increase pasture productivity by stimulating the cycling of N and other nutrients via quantitative and qualitative effects on soil organic matter turnover

In these nutrient-poor ecosystems the efficient recycling and retention of nutrients within the soil-plant system is essential in order to maintain pasture productivity without a detrimental "mining" of the natural resource base Indeed pastures with their known ability to improve soil organic matter contents, are thought to be the best option for an environmentally sound strategy that seeks to increase the productivity of pastoralism and/or agropastoralism of savanna lands

Nutrient recycling is the key to the achievement of these goals in the absence of the facility for agronomically desirable fertilizer inputs In grazed pastures, recycling of nutrients occurs via the return to the soil from animal excreta and plant litter, and also via an internal cycling within the pasture plants

GENERAL RESEARCH OBJECTIVES The general objectives of the two sections involved in nutrient cycling are to quantify the role of the legume in the improvement of soil fertility and nutrient cycling in pastures that are

(i) grazed with different stocking rates,
(ii) established and maintained at different levels of fertilizer,
(iii) grown on soils of two contrasting textures, and
(iv) sown with different grass/legume associations

REFERENCES

Sánchez, P A (1987) Management of acid soils in the humid tropics of Latin America In "Management of acid tropical soils for sustainable agriculture" Sánchez, Stoner and Pushparajah (eds) IBSRAM p 63-107

Toledo, J M (1985) Pasture development for cattle production in the major ecosystems of the tropical American lowlands Proceedings of the XV International Grassland Congress p 75-81, Kyoto, Japan

PROJECT 1 — The role of the legume in soil fertility and nutrient cycling

PERSONNEL — I Rao, M Ayarza, and R Thomas

RATIONALE — Legumes improve soil fertility via chemical and physical improvements of nutrient-poor soils which result from inputs of N from biological fixation and increased amounts of nutrient-rich organic matter when compared with grass-only pastures These characteristics of forage legumes need to be defined and quantified for tropical pastures in terms of i) increased nutrient availability, ii) improved organic matter quality, and iii) enhanced soil biological activity

OBJECTIVES — To assess the effect of legumes on soil fertility and to identify measurable traits in order to define and predict the benefits of the legume for soil fertility improvement

QUESTIONS

1 How much improvement in soil fertility can be achieved in pastures of 1-5 years duration by the introduction of a forage legume when compared with a grass-only pasture?
2 How do different grass-legume associations alter the efficiency of nutrient cycling?

HYPOTHESIS

1 The legume will improve nutrient availability, soil biology and soil physical conditions compared with grass only
2 The type and amount of legume present will alter nutrient cycling efficiency and soil fertility improvement
3 Soil type has an important role in determining the efficiency of nutrient cycling

METHODS

Treatments

Grass + Legume (A)
Grass + Legume (B)
2 replications
2 x 3 = 6 paddocks

Constant factors

Medium stocking rate with paired paddocks of the rotation and blocked pairs The experiment will be carried out on 2 different soil types (Introd 2 and Alegría) using different grass-legume associations on each soil type However, the grass alone treatment will be same on both soil types

Soil type	Association
	1) *B dictyoneura* CIAT 6133
Introd 2	2) *B dictyoneura* CIAT 6133 + *Arachis pintoi* CIAT 17434
	3) *B dictyoneura* CIAT 6133 + *C acutifolium* CIAT 5277
	1) *B dictyoneura* CIAT 6133
Alegría	2) *B dictyoneura* CIAT 6133 + *S capitata* cv Capica
	3) *B dictyoneura* CIAT 6133 + *C acutifolium* CIAT 5277

Fertility

Recommended rates of fertilizer at the time of establishment which includes (kg/ha) P, 20, 50 Ca, 20 Mg, 12 S, 20 K, 2 Zn, 2 Cu, 0 5 B, and 0 2 Mo

Variables

Soil parameters

1) Total amounts of C, N, P, K, S, Ca and Mg
2) Exchangeable levels of N, P, K, S, Ca and Mg
3) Cation exchange capacity
4) Inorganic levels of N, P, and S
5) Mineralization rates for N, P and S
6) Soil organic matter fractionation
7) Soil biological activity
   - mycorrhizae
   - earthworm population
   - soil enzymes
8) Soil structure

All the above parameters will be measured at two different depths in the soil profile (0-5 and 5-20 cm)

Plant parameters

1) Above-ground dry matter distribution and production - with M Fisher
2) Leaf area index - with M Fisher
3) Root dynamics
4) Legume root proportion using stable carbon isotope analysis
5) Root cation exchange capacity
6) Tissue mineral composition
7) Nutrient uptake
8) Nutrient use efficiency
9) Net nutrient removal from the system by the animal weight gain - with C Lascano

METHODS

Soil parameters

Total nutrient levels will be measured using conventional soil analysis Exchangeable nutrient levels will be measured as described in Salinas and García (1985) Inorganic-P and S will be estimated as detailed in Methods of Soil Analysis (Page *et al*, 1982b)

Nutrient mineralization potential will be measured in a grass and grass-legume pastures using 3 methods

1) *in situ* mineralization using PVC cylinders after Raison *et al* 1987, and Adams *et al* , 1989
2) Aerobic incubation of soil samples in pots in screenhouse as recommended by Anderson and Ingram (1989)
3) As above but with undisturbed soils cores taken out of the soil in the same type of cylinders as used in 1)

Mineralization potential will be assessed by the difference in total nutrient contents in soil at the end of the incubation period and that measured at the beginning of the incubation period These methods will be compared at monthly or bi-monthly intervals during the wet season and compared with pasture production assessed by monthly quadrat cuts under cages Mineralization at different soil depths (0-5 cm, 5-20 cm) will also be measured

In subsequent years the best method will be used to assess mineralization potential at the beginning of the wet season (April/May), of different grass and grass-legume pastures across the experimental sites of the core experiment

Soil organic matter fractionation will be carried out according to the methods outlined in the Handbook of Methods by TSBF (1989)

Soil biological activity (mycorrhizae, earthworm population and soil enzymes) will be determined using conventional techniques Soil structure in terms of soil aggregate stability and soil porosity will be determined according to the methods outlined in Methods of soil analysis (Klute, 1982a)

PLANT PARAMETERS

Total dry matter

The dry matter distribution into different plant parts (leaves + stems - roots) will be determined by separating plant parts and drying them in the oven for 72 h at 70°C

Leaf area will be determined using a leaf area meter

Root growth and distribution

Cores of soil will be taken in 20 cm increments to a depth of 80 cm Ten cores will be taken from each replication The cores will be soaked overnight in water containing sodium bicarbonate which will help to disperse the clay Roots will be washed from the soil on a 1 mm sieve and "live" roots separated by hand from the organic matter Root length will be estimated by counting intersections with a 1 cm grid (Tennant, 1975) before drying at 70°C and weighing

Stable carbon isotope analysis
The proportion of legume roots at different depths of soil will be determined by measuring $^{13}C/^{12}C$ ratios using a mass spectrometer according to the methods outlined in Tsvejcar and Boutton (1985)

Nutrient uptake, nutrient harvest index and nutrient use efficiency
These will be measured using the following ratios

- Nutrient uptake efficiency = Nutrient uptake in above ground biomass/Unit root dry weight = mg/g
- Nutrient harvest index = Above ground biomass nutrient content/total nutrient uptake x 100 = %
- Nutrient use efficiency = Above ground biomass yields/Unit nutrient uptake = g/g
- Nutrient dynamics in soil
- Nutrient removal index = amount of nutrient removed from soil-Amount of nutrient added to soil x 100 = %
- Nutrient availability index = Amount of nutrient available (time 1) - Amount of nutrient available (time 2)/Amount of nutrient available (time 1) x 100 = %

Tissue mineral composition Nutrient levels of different plant parts will be measured as described in Salinas and García (1985) Inorganic P and S will be determined according to the conventional methods

Sampling intensity This will be decided based on pasture performance but at least 4 times during the year

Design and analysis The experimental design is a randomized block with 2 replications

- Analysis of variance
- Separation of means by Duncan's multiple range test

REFERENCES

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Raison, R J , Connel, M J and Kanna, P K (1987) Methodology for studying fluxes of soil mineral-N in situ Soil Biol Biochem 19 521-530

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Tsvejcar, T J and T W Boutton (1985) Oecología 67 205-208

PROJECT 2 Influence of stocking rate on nutrient cycling

PERSONNEL I Rao, R Thomas, and M Ayarza

RATIONALE In grazed pastures the return of nutrients to the soil occurs mainly via plant litter (root and shoot) production and decomposition Increasing utilization of the pasture by animals results in less nutrients returning to the soil via litter and more nutrients returning to the soil via excreta The balance between these two recycling routes has a major impact on the net gain or loss of nutrients from the soil-plant system Increasing utilization of the pastures by animals alters the grass-legume balance and also the quantity and quality of plant litter These changes in pasture composition will alter the cycling of nutrients and potential of the system to gain or lose nutrients There is a need to define the grazing strategy required to optimize nutrient cycling in the grass-legume pasture

OBJECTIVES

1 To quantify the pools and fluxes of nutrients through plant litter and excreta under different stocking rates
2 To quantify the rate of uptake of nutrients from the soil under different stocking rates

QUESTIONS

1 How does increasing stocking rate affect the quantity and quality of plant litter?
2 How do changes in litter quality affect litter decomposition?
3 How are nutrient losses from the system affected by stocking rate?
4 How does grazing affect the pools and fluxes of nutrients through the soil-plant-animal system?

HYPOTHESES

1 Stocking rate has a marked effect on plant nutrient uptake and root dynamics
2 Stocking rate is the major management variable that can be manipulated to alter nutrient cycling
3 Stocking rate controls pasture stability and legume persistence
4 Losses of nutrients increase with increasing stocking rate

MATERIALS AND METHODS

Treatments
Grass + Legume
3 stocking rates (light, medium and high)
2 replications
2 x 3 = 6 paddocks

Constant factors
Pasture fertilization level for all the three stocking rates Paired paddocks of the rotation and blocked

pairs The experiment will be carried out on 2 different soil types (Introd 2 and Alegría)

Soil type	Association
Introd 2	*B dictyoneura* CIAT 6133 + *C acutifolium* CIAT 5277
Alegría	*B dictyoneura* CIAT 6133 + *C acutifolium* CIAT 5277

Fertility
Recommended rates of fertilizer at the time of establishment

Variables Soil parameters
1) Total amounts of N, P, K, S, Ca and Mg
2) Exchangeable levels of N, P, K, S, Ca and Mg
3) Inorganic levels of N, P, and S
4) Mineralization rates for N, P, and S
5) Soil structure
6) Loss of nutrients through leaching

All the above parameters will be measured at two different depths in the soil profile (0-5 and 5-20 cm)

Plant parameters
1) Above-ground dry matter distribution and production - with M Fisher
2) Leaf area index - with M Fisher
3) Root dynamics
4) Legume root proportion using stable carbon isotope analysis
5) Tissue mineral composition
6) Nutrient uptake
7) Nutrient use efficiency
8) Litter decomposition (above and below-ground)

Animal parameters
1) Excreta production, decomposition and distribution - C Lascano
2) Net nutrient removal from the system by the animal weight gain - with C Lascano

METHODS

Soil parameters
Total nutrient levels will be measured using conventional soil analysis Exchangeable nutrient levels will be measured as described in Salinas and García (1985) Inorganic-P and S will be estimated as detailed in Methods of Soil Analysis (Page *et al* , 1982b) Changes in soil structure in terms of soil aggregate stability and soil porosity will be determined according to the methods outlined in Methods of soil analysis (Klute, *al* ,

1982a) Nutrient leaching losses will be measured using porous cup techniques (TSBF, 1989)

Plant parameters
Total dry matter The dry matter distribution into different plant parts (leaves + stems + roots) will be determined by separating plant parts and drying them in the oven for 72 h at 70°C Leaf area will be determined using a leaf area meter

Root growth and distribution
Root growth will be measured using three different methods, e g soil coring, soil trenching and root in-growth mesh bag technique (TSBF, 1989, Steen, 1989) Cores of soil will be taken in 20 cm increments to a depth of 80 cm Ten cores will be taken from each replication The cores will be soaked overnight in water containing sodium bicarbonate which will help to disperse the clay Roots will be washed from the soil on a 1 mm sieve and "live" roots separated by hand from the organic matter Root length will be estimated by counting intersections with a 1 cm grid (Tennant, 1975) before drying at 70°C and weighing

Stable carbon isotope analysis
The proportion of legume roots at different depths of soil will be determined by measuring $^{13}C/^{12}C$ ratios using a mass spectrometer according to the methods outlined in Tsvejcar and Boutton (1985)

Nutrient uptake, nutrient harvest index and nutrient use efficiency These will be measured using the following ratios

- Nutrient uptake efficiency - Nutrient uptake in above ground biomass/Unit root dry weight = mg/g
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- Nutrient availability index = Amount of nutrient available (time 1) - Amount of nutrient available (time 2)/Amount of nutrient available (time 1) x 100 = %

Tissue mineral composition Nutrient levels of different plant parts will be measured as described in Salinas and García (1985) Inorganic P and S will be determined according to the conventional methods

Litter production and decomposition

Above-ground litter production will be measured sequentially using paired quadrats (50 x 50 cm) and related to standing crop measurements (Bruce and Ebersohn, 1982) Monthly or bi-monthly intervals will be used as the time unit Litter turnover values will be estimated by the amount of litter accumulating over a given period divided by the litter "standing crop" at the end of a given period

More detailed information on above-ground litter decomposition will be gained from litter bag experiments Ten g of litter (classified into grass and legume components where possible) will be enclosed in nylon bags (30 x 30 x 25 mm approx) with a 1 mm mesh and placed on the soil surface but covered with litter of the particular pasture Bags will be removed at regular intervals (monthly or bi-monthly) and litter material will be dried and analyzed for major nutrients (N, P, K, Ca and Mg) and components known to affect decomposition (e g lignin) Sub-samples will be used for ash determination and results corrected for soil contamination In addition, corrections for spillage and handling losses of material in bags will be made using control bags which will undergo the same handling procedures but which will not be incubated in the field Exponential decay functions will be fitted to the corrected weight loss data to obtain decay constants Litter decomposition characteristics and production will be compared in one of the grass-legume pastures under 3 different stocking rates The experiment will be repeated in the other grass-legume pasture at different times

Assessment of loss of nutrients via leaching
Leaching of nutrients from litter will be estimated by simulating rainfall in laboratory-based experiments using a leaching apparatus consisting of a 50 ml Syringe containing litter and a pump to deliver a known volume of water The leachate will be collected and nutrient content measured (N, P, K, Ca and Mg) These experiments will provide information on the likely effects of abiotic processes (mainly rainfall) on litter compositional changes

Sampling intensity This will be decided based on pasture performance but at least 4 times during the year

Design and analysis The experimental design is a randomized block with 2 replications

- Analysis of variance
- Separation of means by Duncan's multiple range test

REFERENCES

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Tsvejcar, T J and T W Boutton (1985) Oecologia 67 205-208

PROJECT 3 — The role of soil fertility management on legume persistence, pasture productivity and sustainability

PERSONNEL — I Rao, M Ayarza and R Thomas

RATIONALE — Soil fertility management is an important aspect of pasture productivity and sustainability Under low input of fertilizers, the pasture productivity decreases together with the loss of the legume component in the association On the other hand, high soil fertility warrants optimum grazing management to take advantage of the higher availability of nutrients at the root/soil interface and to minimize nutrient losses through leaching Therefore it is essential to know what maintenance level fertility is needed to keep the legume component in an association in order to maintain the efficiency of cycling of nutrients and sustainability of the pasture

OBJECTIVES — To assess the role of soil fertility management on (i) animal productivity, (ii) pasture productivity, (iii) legume persistence, and (iv) nutrient cycling

QUESTIONS

1) Is the presence of legume in an association influenced by soil fertility management?
2) What is the effect of soil fertility management on the cycling of nutrients within the system?
3) What type of fertility management will lead to a sustainable pasture production (in terms of animal gains, nutrient losses and cycling)?

HYPOTHESES

1) Higher soil fertility (high or maintenance fertility) than pasture establishment fertility, will increase the persistence of the legume in an association
2) Higher soil fertility (high or maintenance fertility) will increase the efficiency of nutrient cycling by maintaining the legume component in an association Pasture fertility level will have the risk of losing the legume component
3) Although the high (crop) fertility level will increase pasture productivity over short-term, the maintenance level of fertility will lead to better sustainability of the association

MATERIALS AND METHODS

Treatments

Fertility levels

1) Pasture fertility (kg/ha 20 P, 50 Ca, 20 Mg, 12 S, 20 K, 2 Zn, 2 Cu, 0 5 B, and 0 2 Mo)
2) High (crop) fertility (kg/ha) 60 P, 150 Ca, 60 Mg, 24 S, 100 K, 2 Zn, 2 Cu, 0 5 B, 0 2 Mo)

3) Maintenance fertility (pasture fertility level + ? additional fertilizer level)

2 replications

2 x 3 = 6 paddocks

Constant factors

Medium stocking rate with paired paddocks of the rotation and blocked pairs The experiment will be carried out on 2 different soil types (Introd 2 and Alegría)

Soil type	Association
Introd 2	B dictyoneura CIAT 6133 + C acutifolium CIAT 5277
Alegría	B dictyoneura CIAT 6133 + C acutifolium CIAT 5277

Variables

Soil parameters

1) Total amounts of N, P, K, S, Ca and Mg
2) Exchangeable levels of N, P, K, S, Ca and Mg
3) Inorganic levels of N, P, and S
4) Mineralization rates for N, P, and S
5) Soil organic matter levels
6) Soil biological activity
   - mycorrhizae
   - earthworm population
   - soil enzymes
7) Soil structure
8) Nutrient losses by leaching

All the above parameters will be measured at two different depths in the soil profile (0-5 and 5-20 cm)

Plant parameters

1) Above-ground dry matter distribution and production - with M Fisher
2) Leaf area index - with M Fisher
3) Root dynamics
4) Legume root proportion using stable carbon isotope analysis
5) Tissue mineral composition
6) Nutrient uptake
7) Nutrient use efficiency

Animal parameters

Net nutrient removal from the system by the animal weight gain - with C Lascano

METHODS — As for Project 2

Sampling — This will be decided based on pasture performance but at least 4 times during the year

Design and

analysis — The experimental design is a randomized block with 2 replications

- Analysis of variance
- Separation of means by Duncan's multiple range test

PROJECT 4 — Measurement of N_2 fixation by tropical forage legumes

PERSONNEL — R Thomas

RATIONALE — In tropical pastures which are frequently limited by N supply, the input of biologically fixed N by legumes is the main driving force for productivity in the absence of other N inputs such as fertilizer Most measurements of N_2 fixation have been done by indirect means and only relatively recently have the techniques of ^{15}N isotope dilution become more widely available Estimates of rates of N_2 fixation in tropical pastures are needed in order to determine potential productivity and sustainability of pasture systems in savanna lands The proposed study will quantify rates of N_2 fixation as a function of legume content or cover in pastures Thus it may be possible to predict N input from fixation by some simple legume parameter

OBJECTIVES — To quantify rates of N_2 fixation and relate them to some legume parameter such as legume leaf area, % ground cover, % legume leaf dry matter content of the sward

QUESTIONS

1. How much N_2 can forage legumes fix under sward conditions?
2. Is there a correlation between legume leaf area, dry weight, % coverage and rate of N_2 fixation?
3. What proportion of the legume-N is fixed N_2 under different soil fertility levels

HYPOTHESES

1. Legume N_2 fixation is a function of legume productivity
2. Soil fertility determines the proportion of legume-N obtained from fixation

MATERIALS AND METHODS

N_2 fixation will be measured using ^{15}N isotope dilution in plots of grass-legumes separate from the main core experiment Swards with different legume contents will be prepared by using different grass-legume seeding rates The grass-legume associations used will be the same as those in the core experiment Separate grass-only plots will also be established These will be used as non-fixing controls assuming that the rooting profiles are similar to those of the legumes Preliminary work on the rooting profiles of grasses and legumes will be necessary to check this assumption

A cutting regime will be employed to control grass-legume leaf areas N_2 fixation will be measured by applying small amounts 3 kg N ha^{-1} of ^{15}N labelled ammonium sulphate to grass-legume and grass-only plots The comparison between grass in the grass-only and in the grass-legume plots will indicate if any N transfer has occurred between the legume and the grass providing certain assumptions concerning rooting profile and soil N pools hold (e g Witty, 1983) Herbage will be harvested after approximately one month and amounts of N_2 fixed and proportion of legume-N from fixation will be estimated by standard isotope dilution techniques Results will be expressed per plant, per unit legume leaf area, and per unit legume leaf dry weight (Ledgard and Peoples, 1988)

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PROJECT 5 Internal remobilization of nutrients by tropical pasture plants

PERSONNEL R Thomas, I Rao and M Ayarza

RATIONALE An analysis of the N cycle of grazed pastures has suggested that differences in the ability of pasture plants to translocate N from senescing above-ground tissues to new growing tissue could have a large impact on the amounts of N required to balance the expected losses of N (Thomas, 1990) Internal remobilization has been a neglected aspect of the N cycle but has been recognized as an important component of natural ecosystems (Woodmansee, 1984) The proposed study will compare remobilization of nitrogen and other nutrients in grass and legume species used in the core experiment

OBJECTIVES To quantify the internal recycling (remobilization) of N and other nutrients in tropical grass and legume species

QUESTIONS
1 How much N and other nutrients can be recovered from senescing leaf tissue?
2 Are there differences between grasses and legumes?
3 How does grazing (defoliation) affect internal remobilization?
4 How does increased fertility affect internal remobilization?

HYPOTHESES
1 Internal remobilization of nutrients is a function of soil fertility and severity of grazing
2 Legume persistence is affected by internal remobilization

MATERIALS AND METHODS

The initial approach will be to simply collect green and senescent leaf tissue from grass and legume plants in grazed pastures Data from other projects on leaf appearance, leaf weights and numbers per plant and plant population numbers will be used to obtain crude estimates of the amounts of nutrients that may be recycling via this process

A more detailed study will be done on a few selected plant species using the techniques of tiller tissue turnover (Thomas et al , 1990) Rates of leaf senescence and remobilization will be measured on marked laminae on grazed and ungrazed plants in a pasture grazed at 3 stocking rates As the grass will be the major component in the grass-legume sward it will be studied in detail before the legume Rates of senescence and remobilization will be compared in urine-affected and unaffected pasture to obtain information on how increased fertility affects senescence and remobilization

Initially only one grass-legume pasture will be studied until the methodology has been defined

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PROJECT 6 N transfer between legumes and grass

PERSONNEL R Thomas

RATIONALE Legumes are used in pastures as the source of N and because most pastures are limited by N supply The amounts of N needed to maintain a productive and sustainable pasture vary with the degree of pasture utilization but for tropical pastures it has been estimated that a range of 15-158 kg N/ha/year would suffice (Thomas, 1990) It is widely assumed that fixed N in the legume is eventually transferred to the grass via soil pools of N However there is a little evidence of this transfer, even after 6 months (Ledgard et al , 1985) Few studies have been reported on tropical pastures although rates of fixation of the order required have been reported (Cadisch et al , 1989) The proposed study will quantify rates of transfer of N from legume tissues to grass plants using methodology similar to that used for decomposition studies

OBJECTIVES To quantify the transfer of N from legume tissues to grass plants

QUESTIONS
1 How rapidly is legume tissue decomposed in soil?
2 How much N becomes available for uptake by grass plants?
3 What % of legume-N is taken by associated grasses?

HYPOTHESIS
1 N transfer is a function of the quantity and quality of legume litter

MATERIAL AND METHODS

Legume plants will be grown in sand/perlite in the glasshouse and fed ^{15}N-labelled ammonium sulphate to increase the ^{15}N content of the tissues Plants will however be nodulated Root, nodule and senesced leaves will be collected periodically dried and stored as a source of legume litter Litter from roots, nodules and leaves will be placed in litter bags and incubated on the soil surface (leaves) and at 5-10 cm depth (roots and nodules) in selected areas of the grass-only pastures in the core experiment These areas will be caged to prevent grazing Soil and grass samples will be collected at monthly intervals and analyzed for ^{15}N content Litter bags will also be collected at monthly intervals to determine rates of decomposition of legume tissue as before Two sets of bags will be used, one for the measurement of decomposition, the other for measurement of ^{15}N transfer to the associated grass Grass will be harvested by cutting to a pre-determined sward height Soil cores will be taken at the end of the experiment to determine root mass and ^{15}N content

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PROJECT 7 — Rhizobium survival in grazed grass-legume pastures

PERSONNEL — R Thomas et al

RATIONALE — Benefits from inoculation of forage legumes with Rhizobium strains in ungrazed experiments usually decline after or 2 years either because indigenous strains outcompete the introduced strain or the latter fails to survive in sufficient numbers to reestablish an effective symbioses in regenerating legume plants On the other hand, Rhizobium numbers appear to be positively correlated with legume plant density There is a need to determine the survival potential of introduced Rhizobium strains as related to legume persistency and the effects of increased soil fertility brought about by the legume and/or increased levels of fertilizer for maintenance and any introduction of pasture-crop rotations

OBJECTIVES

1 To monitor the survival of introduced strains of Rhizobium into legume-based pastures

QUESTIONS

1 Can introduced strains persist in the absence of legume/persistence?
2 Do indigenous strains out compete introduced strains with time?

HYPOTHESES — The survival of introduced strains depends on the establishment and persistence of the host legume plant

METHODS

Treatments	Grass + legume - 2 associations B dictyoneura + C acutifolium 2 replications 2 soil types 2 x 2 x 2 = 8 paddocks
Fertility	Pasture maintenance fertility
Variables	Legume plant numbers Rhizobium populations
Methods	Quadrats for legume plant population densities Serological techniques for Rhizobium strain typing as currently used with addition of ELISA techniques presently under test

SECTION ECOPHYSIOLOGY

PERSONNEL M J Fisher

RATIONALE For any pasture to be stable in the longer term, it is necessary that its component species remain persistent The factors that are responsible for persistence of pasture species are not clearly understood, but it is self-evident that most plants have only finite life spans Therefore for a component to maintain its presence in a pasture, the death of individual plants must at least be matched by recruitment of new individuals, whether by the establishment of seedlings or by vegetative reproduction through stolons or rhizomes Clearly, then, it is necessary to determine which of these processes is critical to the survival of the component, preferably under different systems of management in order to determine the effects of management

It is clearly unrealistic to select just one factor that in prospect will dictate success or failure for all species Each species has its strengths and weaknesses, and it is the balance between them that is important The challenge in a program of germplasm evaluation is to be able to identify early in the evaluation process which factors are vital for any particular species, and determine whether there is any possibility that the deficiencies can be compensated for by management, by further search (or selection), or by breeding

Initially, it is necessary to identify the critical factors in the growth of the components of a particular association, and how they are affected by grazing management Initially, work will be concentrated on measuring the population dynamics, such as

sward composition

population dynamics as influenced by grazing management and nutrient status

- plant longevity
- seed bank dynamics and recruitment

dynamics of residual leaf area and growing points as influenced by grazing management and nutrient status

the influence of patchiness

Together, these studies will allow a retrospective estimate of the critical factors responsible for the success or otherwise of a particular genotype (species) They will provide data critical to the modelling of tropical pastures under grazing, and will be key data for input to the modelling exercise, which will synthesize the activities within the group

GENERAL RESEARCH OBJECTIVES

To understand the factors responsible for the persistence of legumes and grasses grown in association under grazing, with particular reference to the relations between the component of the association as influenced by

1 The photosynthetic characteristics of the species including the responses of photosynthetic rates, stomata and specific leaf area to light, nutrient and water stresses

2 The gross morphological behavior of the species (canopy architecture, distribution of meristems) and their influence on plant/plant relations

3 The effects of grazing animals by defoliation (differential consumption of leaf area and meristems)

4 Reproductive behavior, including flowering, dynamics of the seed bank, germination, and seedling establishment

5 Longevity of the components

6 Competition for scarce resources

PROJECT 1 The population dynamics of species within mixed legume-grass associations as a function of the number of growing points

PERSONNEL M J Fisher

RATIONALE It has been shown that for each of a wide range of legumes in a pasture, the number of growing points consumed by grazing cattle is a simple function of the grazing pressure expressed in terms of the metabolic weight of the grazing cattle per unit of green dry matter on offer (Clements 1989) The relation is characteristic for the species concerned, although it is plausible that for a given life form of plant (trailing, procumbent, intermediate) the relation may be consistent across species

OBJECTIVES To document the consumption of meristems of the components of associations of contrasting legume/grass associations

To establish relationships between the consumption and the grazing pressure

HYPOTHESES In a grazed pasture,

1 The number of growing points is fundamental to the survival of a species in a pasture

2 The number of growing points depends upon their rate of production and their rate of consumption

3 The rate of production of growing points is a function of the species concerned

4. The basic rate of production of growing points within a species is controlled by its growth rate

MATERIALS AND METHODS

Within the central core experiment in the contrasting associations/sites at different stocking rates

1. To document the changes in the dynamics of the populations of growing points of the different species

2. Monitor consumption and production of growing points

3. Relate the rate of production of growing points to plant growth rate

PROJECT 2 Studies of the growth rate of the component species within mixed legume-grass associations as controlled by their leaf area, photosynthetic characteristics, and stress responses

PERSONNEL M J Fisher

RATIONALE It has been shown under grazing that for a range of Brachiaria species and for both Desmodium ovalifolium and Arachis pintoi, that within the grasses and within the legumes, and for a particular grazing pressure, growth rate could be expressed as a function of mean leaf weight during the regrowth period (Fisher and Thomas, 1989) The slope of this relation is net assimilation rate, and is a measure of the efficiency of dry matter production There were departures from the common relation at times that could be explained by external factors such as extremely wet weather (cloudiness and/or waterlogged soil) This relation suggests the overwhelming effect of leaf area as controlling growth rate, although it is unlikely to be consistent for all legumes or all grasses Moreover, the departures from the relation suggest that factors controlling photosynthesis may operate to modify it

OBJECTIVE To investigate which are the critical factors that control the growth rates of the components of a pasture

What are the mechanisms by which they operate and the functional relationships between them and growth rate

HYPOTHESES In a grazed pasture

1 Growth rate is controlled by the leaf area, and its activity

2 The activity of leaf area is controlled by the photosynthetic rate

3 Photosynthetic rate is controlled by
   the status of the most limiting nutrient,
   the basic level of metabolic activity of the plant (internal limitations),
   light levels,
   water status

4 The efficiency of allocation of carbon to meristems directly affects the tolerance of a species to grazing

5 Residual leaf area, which controls initial growth rate following grazing, is a function of
   the rate of production of leaf area,
   the rate of consumption of leaf area,
   the rate of senescence

6 The rate of consumption of leaf area and growing points is controlled by

the grazing pressure,
the accessibility of the leaves and growing points,
a selectivity factor

MATERIALS AND METHODS

1 Determine in the species of interest (the legumes Stylosanthes capitata, Centrosema acutifolium, and Arachis pintoi, and the grass Brachiaria dictyoneura) the response functions of photosynthesis to light, and the influence on them of nutrient deficiencies (initially phosphorus, potassium, and nitrogen), and shortage of water These studies will initially be carried out in the laboratory at Palmira, but supplemented by measurements in the field at Carimagua, using portable apparatus

2 Determine growth rates in the pastures in the core experiment, which will be grazed rotationally, using conventional clipping at the start and end of the rest periods in the treatments subjected to different grazing pressures

3 In controlled experiments, simulate grazing to by removing leaves to give different amounts of residual amounts of leaf area, and determine the effects on subsequent growth rates Determine the effects of the "quality" (age, functionality) of leaf area and growing points

METHODOLOGICAL CONSIDERATIONS

Can growth rate be estimated more easily than by conventional clipping techniques?
by measuring leaf area expansion over short periods, say 5 days
regrowth over short periods

PROJECT 3 Plant longevity and the factors that control it

PERSONNEL M J Fisher

RATIONALE It is difficult to make generalized hypotheses about the reasons for plant death Questions about the existence or not of a death hormone, or the applicability of alternative hypotheses lie outside the scope of this project Nevertheless, in order to explain observations of the population dynamics of the components of an association, and to permit prediction of the behavior of an association under grazing, it is necessary to define longevity for a particular species (or genotype) in terms of measurable factors It is likely that any particular genotype has a characteristic mean lifespan, from which the lifespan of individual plants will differ in a predictable (on average) manner, but which will define the maximum lifespan of a particular cohort within a pasture It is not clear whether premature death under grazing may be explained in terms of loss of growing points, or whether it is necessary to invoke some other factor

OBJECTIVES To document the population dynamics of pastures of contrasting associations on the same soils at different stocking rates, and
the same associations on contrasting soils, at different stocking rates and at different levels of fertility

To explore alternative hypotheses that may explain the reasons for premature plant death It is clear that some methodological work is needed

HYPOTHESES In a grazed pasture,

1 Each plant has a critical level of reserves for regrowth below which it will die

2 The level of reserves is the outcome of the balance between residual leaf area, and its rate of removal, and root growth

3 The reserves referred to above are primarily soluble carbohydrates stored in specific organs (stem bases or tap roots) When respiration exceeds synthesis, reserves decline If reserves are exhausted while respiration exceeds synthesis, then the plant dies

MATERIALS AND METHODS

Within the different associations/soils and stocking rate treatments, monitor plant population dynamics (as outlined in Project 2 When there are indications of declining populations, make measurements of soluble carbohydrates in the storage organs

Supplementary experiments with plants of each of the associations subjected to varying levels of residual leaf area to determine the relations between carbohydrate reserves, residual leaf area, and plant survival

METHODOLOGICAL PROBLEMS

To what extent does uptake mask measurement of reserves?

What determines the innate longevity of plants - monocarpism in annuals, but in short-lived perennials?

Can plant height be used as a measure of "sward state" and hence of reserves?

Can regrowth potential of the components of an association be determined by mimicking frequency and severity of grazing?

PROJECT 4 Population dynamics of species within mixed legume-grass associations as a function of seed production, the soil seed bank, germination and establishment

PERSONNEL M J Fisher

RATIONALE It is self-evident that if plants of a particular species in an association that die are not replaced by new ones, then the population will decline The inputs and losses from the soil seed bank determine its size, on which, for a particular species depends the ability of it to provide new recruits for the adult population Unfortunately, demographic studies require several life cycles of the plants concerned, and may take many years to complete Although they usually allow the generation of hypotheses about the factors that control the survival of the components, these are commonly formulated only after the component of interest has already failed An obvious requirement is the development of methodology that would allow the rapid assessment as to which process is critical to the success of a component of any particular association

OBJECTIVES To relate the size of the soil seed bank to the inputs and outputs

To relate seed production to sward state and species

To relate seed losses to factors associated with grazing pressure and environmental factors

To develop appropriate methodologies to allow rapid assessment of factors critical to the survival of the components of particular associations

HYPOTHESES In a grazed pasture,

1 The production of seed is an innate characteristic of a particular species, and within any species, a characteristic of genotype within any particular location

2 The level of the seed bank is a function of the amount of seed produced, and its losses

3 Seed production is controlled by residual leaf area and growing points at critical periods of the year

4 Germination is a function of
- environmental conditions,
- size of the seed bank,
- germinability of the seed in the seed bank,
- soil surface characteristics, and
- depth of seed burial (i e the vertical distribution of seed)

5 Losses are controlled by
the death rate of seed (diseases, physical damage, seed age),
rate of seed predation,
dormancy and hardness of the seed coat, and
longevity of the seed

6 Recruitment is controlled by
the rate constant of germination,
survival of seedlings,
trampling (grazing pressure, environmental conditions)
compaction of the surface soil,
plant/plant competition, as affected by the level of defoliation of associated plants, especially adults.

7 Growth rate and death rate of seedlings are controlled by the same factors as mature plants, except that reserves and resources are much less

MATERIALS AND METHODS

1 Within the core experiment establish relations between seed production, the size of the seed bank, the grazing treatment, environmental factors, and the rate of recruitment of seedlings

2 Supplement field observations with studies of seedling competition, and establishment

SECTION PASTURE QUALITY AND PRODUCTIVITY

PERSONNEL CARLOS E LASCANO

GENERAL RESEARCH OBJECTIVES

1 Establish relationships between environmental factors (soil fertility, rainfall distribution), grazing management, and intake (qualitative and quantitative)

2 Establish relationships between pasture attributes (i e sward structure, botanical composition, forage availability and density, forage quality), and intake (qualitative and quantitative)

3 Establish relationships between voluntary intake and LWG

4 Provide data on intake and excreta return to construct nutrient budget in grazed pastures

PROJECT 1 PLANT/ANIMAL RELATIONSHIPS 1 QUALITATIVE INTAKE IN GRASS/LEGUME PASTURES

PERSONNEL CARLOS E LASCANO

Rationale Animal production in grazed pastures is a function of digestible nutrient intake, which in turn is influenced by animal selectivity The degree of selectivity exhibited by the grazing animals is related to plant attributes (species, chemical composition), plant environment (soil type, soil fertility, rainfall distribution) and grazing management (relative availability of species, sward structure)

Objectives To establish relationships between legume selectivity and legume proportion in the total biomass and in different strata of the canopy, as affected by grazing management, soil texture, soil fertility and rainfall distribution

Questions Does the relationship between legume proportion in the diet and proportion in the forage on offer change with (1) species (i e palatability), (2) soil texture, (3) soil fertility, (4) rainfall distribution, (5) legume distribution in the canopy?

Hypothesis 1 The relationship between proportion of legume in the diet and proportion in the forage on offer changes with legume distribution in the canopy 2 Legume proportion in the diet is higher in the dry than wet season, but this could be modified by sward structure
3 The relationship between proportion of legume in the diet and proportion of legume on offer (selection index) will change with species

Treatments Site 1

(1) grass/legume (A y B) at three stocking rates with pasture fertility and (2) grass/legume (A) at medium stocking rate with crop fertility

Total plots 7 x 2 reps = 14

Treatments Site 2

(1) Grass/legume (A y B) at three stocking rates with pasture fertility, (2) grass/legume (A y B) at medium stocking rate with crop fertility
Total plots 8 x 2 reps = 16

Total plots site 1 + 2 = 30

Description of pastures

At the two sites (site 1 = sandy soil and site 2 = heavy soil) the common grass will be *B dictyoneura* cv Llanero In the sandy soil (site 1) the legumes will be *C acutifolium* cv Vichada (Asoc A) and *S capitata* cv Capica (Asoc B) In the heavy soil (site 2) the legumes will be *C acutifolium* cv Vichada (Asoc A) and *A pintoi* (Asoc B)

Variables

1 Legume proportion in the total biomass
2 Legume proportion in three stratas of the canopy (high, medium and low)
3 Legume proportion in the diet by $^{13}C/^{12}C$ ratios in feces, grass and legume on offer

Methods

The legume proportion in the forage on offer and diet selected by grazing animals will be measured four times a year (February, May, August and November) In each sampling period the legume proportion in the pasture and diet will be estimated in paddocks 2 and 4 of the rotation before and after grazing

Total legume proportion in the biomass will be estimated by cutting and hand-separation of the forage in quadrats placed in transects The distribution of legume in the canopy horizon will be estimated by stratified sampling in random quadrats Samples cut at the high, medium and low stratas will be hand-separated for grass and legume leaf and stem

The botanical composition of the diet will be estimated with permanent animals grazing the pastures Fecal and forage samples (grass and legume) taken on days 2, 4 and 6 of occupation of paddocks 2 and 4 will be analyzed for $^{13}C/^{12}C$ ratio

PROJECT 2 PLANT/ANIMAL RELATIONSHIPS 1 QUANTITATIVE INTAKE IN GRASS AND GRASS/LEGUME PASTURES

PERSONNEL CARLOS E LASCANO

Rationale Animal production in grazed pastures is a function of digestible nutrient intake, which in turn is influenced by sward characteristics (i e accessibility), plant factors (i e digestibility cell wall content) and animal factors (i e rumen capacity) In addition, nutrient intake may be depressed by low forage availability (i e high stocking rate), low legume proportion in the pasture and nitrogen deficiency in the grass on offer

Objectives To establish relationships between pasture attributes (i e sward density, botanical composition, forage availability and forage quality) and voluntary intake

Questions Does voluntary intake change with (1) sward density, (2) botanical composition of the forage on offer (i e grass/ legume ratio), (3) availability and (4) forage quality (i e crude protein and digestibility levels)

Hypothesis Forage intake by grazing animals is a function of pasture attributes such as availability accessibility and quality (i e CP and digestibility levels)

Treatments Sites 1 and 2

(1) grass/legume (A y B) at three stocking rates with pasture fertility and (2) grass alone at middle stocking rate

Total plots, site 1 and 2 = 14

Description of pastures

At the two sites (site 1 = sandy soil and site 2 = heavy soil) the common grass will be B dictyoneura cv Llanero In the sandy soil (site 1) the legumes will be C acutifolium cv Vichada (Asoc A) and S capitata cv Capica (Asoc B) In the heavy soil (site 2) the legumes will be C acutifolium cv Vichada (Asoc A) and A pintoi (Asoc B)

Variables (vegetation)

1 Forage availability (kg/ha) (total and green dry matter)
2 Sward bulk density (kg/ha/cm)
3 Forage composition
   - Leaf stem dead matter
   - Grass legume
4 Forage quality (grass leaf and legume leaf)
   - Crude protein
   - IN VITRO digestibility
   - Cell wall content
   - Indigestible cell wall
   - Ash (mineral content)

Variables (animals)

1 Quality of ingested forage (C P , IVDMD and ash)
2 Fecal output (external slow release cr oxide capsules) of intact animals
3 Digestibility (<u>IN VITRO</u> of extrusa samples and using internal marker-INDF)
4 Eating rate of fistulated animals (bite size/unit time)

<u>Methods</u>

Intake and forage on offer attributes will be measured four times a year (February, May, August, and November) In each sampling period forage attributes will be measured in paddocks 2 and 4 of the rotation before and after grazing, as in <u>Project 1</u>

Quality of ingested forage will be estimated in extrusa samples collected with 3 esophageal fistulated steers/ paddock on day 1, 4 and 7 of occupation of each paddock Fecal output will be estimated by dosing each animal a slow cr release capsule on day 1 in paddock 1 of the rotation Fecal samples will be collected on day 4 and 6 on paddocks 2, 3 and 4 Fecal output will be calculated by

$$\frac{\text{Cr output in feces (g/day)}}{\text{[Mean cr] in feces (g/g DM of feces)}}$$

Digestibility will be estimated by analyzing the INDF (indigestible neutral detergent fiber) of extrusa and fecal samples collected in paddocks 2 and 4

Eating rate will be estimated in one of the paddocks in each treatment by pluging the esophagous of fistulated steers and determing dry matter ingested/unit time

SECTION MODELLING

PROJECT Modelling a legume/grass pasture in the lowland tropics

PERSONNEL J H M Thornley, A N Other

RATIONALE No model exists that describes the relation between the components of a tropical pasture However, a model of a temperate pasture (the Hurley pasture model, Thornley and Verberne 1989) has been evaluated to determine its suitability for application to grazed legume/grass pastures in the lowland tropics

The Hurley pasture model is concerned with the dynamics of the carbon and nitrogen pools and flows in a grazed ryegrass monoculture under temperate conditions, and to relate these to environmental and management variables It achieves this by means of a process-based approach that integrates animal, plant and soil sub-models It appears that the model is not sufficiently relevant to legume/grass pastures for the lowland tropics for its direct application to be useful Deficiencies in it for this purpose are

1 Phosphorus is not represented This is an important nutrient in the lowland tropics, ranking almost equally with nitrogen

2 It does not include an explicit representation of meristematic tissue when calculating growth This means that the separate production of stolons, rhizomes and seeds, which have differing importance and survival in different plants, is not handled explicitly, these processes are significant for the dynamics and persistence of grazed legume/grass pastures

3 N-fixation is only represented implicitly, an explicit and appropriate process representation is required for tropical legume/grass pastures

4 Animal intake preferences (legume vs grass) play no role in the monoculture Hurley model

5 There is no representation of two species that compete for light, nutrients, and water, and have different growth habits and digestibilities, as in legume/grass pastures

6 The animal sub-model is for mature sheep, and needs substantial changes to provide realistic predictions of live-weight gain and pasture productivity for grazing beef cattle

THE CONSTRUCTION OF A PROTOTYPE TROPICAL PASTURE MODEL

The model that will be required for grazed legume/grass pasture is considerably more complex than the Hurley temperate pasture model, and as outlined above, will require much de novo programming Just as the experimental program will of necessity be incomplete, a tropical pasture model can only represent a limited amount of detail about the real world, and it will therefore be inaccurate at some level of precision However, a good consensus has been achieved about what should go into such a model, at least initially, and the task of constructing the model, while substantial, appears to be feasible

Very approximate estimates have been made of the time required to modify and extend the Hurley model in the respects listed above for the needs of the PDU, These estimates do not include time required for model exploration (including further minor modification where required) and its application to currently available data and data arising from the core experiment, both of which may be substantial

1 Phosphorus pools, fluxes and P-dependent processes 60 days

2 Meristem representation of growth via rhizomes, stolons and seed production 30 days

3 Nitrogen fixation - explicit representation 5 days

4 Animal intake preferences 10 days

5 Legume and grass represented separately by independent plant sub-models, competing for light, water and soil nutrients 80 days

6 Potassium leaching 1 day

7 A dynamic animal growth model 6 days

The total is 192 days, say 200 days

It is suggested that a step-by-step procedure for carrying out this work might be

1 Construct a monoculture model, applicable to a grass or to a legume, incorporating the modifications outlined above

2 Apply (1) to a legume/grass sward by bringing together a legume sub-model and a grass sub-model, making appropriate changes for competition etc

PROPOSED ORGANIZATION OF THE MODELLING PROJECT

The estimate of the 200 days is based on the work being done by Dr Thornley himself However, he has other on-going commitments with the Institute of Terrestrial Ecology, and while he might be able to undertake such a commitment if it were spread over four years (50 days per year), it seems doubtful that this rate of progress would be sufficient to maintain the enthusiasm and commitment of the PDU staff, and to provide timely interaction as the results from the Core experiment are forthcoming

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AN INTEGRATED APPROACH TO SOIL-PLANT-ANIMAL INTERACTIONS ON GRAZED LEGUME-BASED PASTURES ON TROPICAL ACID SOILS

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ABSTRACT

Legume based pastures developed by the Tropical Pastures Program (TPP) of CIAT give spectacular increases in both stocking rates and animal live weight gains on the savannas of Latin America A team within the TPP is addressing the problems of their management for legume persistence and soil plant animal interactions using as its focus a grazing experiment on two oxisols of contrasting texture on the Colombian Llanos The objective is to *model* the pastures to forecast the effect of management options on long term persistence and nutrient cycling in grazed legume grass associations in the Latin American savannas

INTRODUCTION

The tropical Latin America savannas in the Colombian and Venezuelan Llanos and the Brazilian Cerrados cover over 200 million ha They have infertile acid soils carry poor quality grasslands of low productivity and are used for extensive cattle ranching although cropping has become important in parts of the Cerrados and the Venezuelan Llanos Increasing urban populations together with poverty and degradation of other marginal lands require that more meat milk and crops be produced in the savannas in sustainable systems

The Tropical Pastures Program (TPP) of CIAT has developed low input grasses and legumes which are tolerant of the difficult edaphic and biotic environments to increase productivity of the savannas Legumes play a key *role by fixing nitrogen by stimulat* ing cycling of other nutrients and by enhancing both the quantity and quality of forage

Legume based pastures developed by the TPP give spectacular increases in animal production compared with native savannas (Table 1) They are also very important to recuperate lands degraded by imprudent cropping or grazing (CIAT 1991)

Table 1 Liveweight gains of cattle on native savanna and le gume/grass pastures on the Colombian Llanos

Pasture	SR	Liveweight gain		
			dry[b]	wet[b]
	head/ha	*kg/ha/yr*	*g/head/day*	
Native savana	0 1 0 2	15 20		
B humidicola/	2		272	572
A pintoi[d]	3		186	406
B dictyoneura/	2		469	525
A pintoi[d]	3		507	525

stocking rate [b] season R Vera unpublished data [d] CIAT 1990

However they are often unstable and the management to maintain an adequate (itself poorly defined) proportion of legume is little understood The goal therefore is to formulate appropriate management to ensure their persistence in the longer term

THE PROBLEM AND THE APPROACH

Temperate cropping systems are generally quite well understood In contrast pastures are more complex because several different species involved there is far less scope to manipulate the conditions for plant growth *the time scale is much* longer and grazing influences them profoundly Moreover because tropical grasses and legumes have different physiologies tropical pastures are more difficult to manage than temperate pastures Given this traditional empirical research requires large resources and can make only slow progress usually without any clear understanding of the processes critical to the system

Some temperate pastures have been successfully modelled for *example* the Hurley model (Thornley and Leverne 1989) The models synthesize knowledge of the physiology of the constituent plants how they react to the environmental factors that limit their growth and to grazing in terms both of herbage consumption and nutrient cycling By mimicing the behavior of grazed pastures the models show qualitatively how management affects the relationships between the components and also identify key processes Modelling is thus a key part of our approach

CIAT specialists in nitrogen economy nutrient cycling plant nutrition animal production ecology and eco *physiology defined the* project which was reviewed by an external international panel in 1990 The objectives are to understand the soil plant animal interactions so as to model the system in enough detail to allow extrapolation to other sites in the same ecosystem The modelling of the system by JHMT uses the Hurley model as a base

THE EXPERIMENT

A *field experiment* was established at the CNI Carimagua Station in the Colombian Llanos (lat 4°30 N long 71°19 W alt 175 m) in mid 1990 with promising legume/grass associations Carimagua is in the iso hyperthermic savannas (Cochrane and Jones 1981) and has a seasonally dry climate with 2200 mm of rain falling April November and uniformly high temperatures throughout the year (mean maxima 31 7°C and 33 6°C mean minima 18 6°C and 16 4°C in the wet and dry seasons respectively) The experiment is on two Oxisols soils a sandy loam with 66% sand and a clay loam with 24% sand *(0 20 cm depth) On* each site the treatments form an incomplete factorial (nine treatments on the sandy loam and eleven on the clay loam) with two replicates

In summary the treatments are

A Initial fertilizer at pasture rates of P20 Ca50 Mg20 S12 K20 Zn2 Cu2 B0 5 Mo0 1 (kg/ha) but no maintenance fertilizer at three

(1) *Brachiaria dictyoneura* alone at medium SR
(2) *B dictyoneura/Centrosema acutifolium*
(3) *B dictyoneura/Stylosanthes capitata* (on the sandy soil)
B dictyoneura/Arachis pintoi (on the clayey soil)
} X { low SR, medium SR, high SR

stocking rates (SR)

B Two fertilizer treatments both grazed at the medium SR only

(4) *Bd/C acutifolium*
(5) *Bd/A pintoi* (on the clay soil only)
} X { Initial fertilizer plus maintenance; three times initial fertilizer but no maintenance

Table 2 Stocking rates used in the experiment

Soil	Sandy loam	Clay loam	
Association	Both	Bd/Ca	Bd/Ap[b]
		head/ha	
Low SR	1 0	1 5	2 0
Medium SR	1 5	2 0	2 5
High SR	2 0	2 5	3 0

B dictyoneura(Bd)/C acutifolium [b] *Bd/A pintoi*

Within each replicate treatments are divided into four paddocks randomized by pairs and each paddock is grazed by three animals in a rotation of 7 days occupation 21 days rest The stocking rates differ between association and site (Table 2)

The treatments are inevitably compromises between the best adapted germplasm for particular sites and the greater certainty of successful performance For example *S capitata* performs better on sandy soils while *A pintoi* is better on heavier soils *C acutifolium* has wider adaptation to soil texture and is the common legume on both sites Similarly *B dictyoneura* was chosen for both sites despite its susceptibility to spittle bug because although *Andropogon gayanus* is better on sandy soils it can be destroyed by leaf cutter ants

Pasture composition yield and cover are estimated before the animals enter each plot and after they leave Liveweight gain is measured each five weeks and at the same time quality of the forage on offer is estimated by plucked samples Diet composition is estimated using carbon isotope discrimination and animal consumption using dye markers Data of nitrogen accumulation soil nutrient levels root distribution litter yields stratified yield of plant components and nutrient concentrations are taken in one paddock of each treatment in the early and late wet season and mid dry season The experiment with some satellite studies also serves as a site for the Tropical Soil Biology and Fertility network

RESULTS AND DISCUSSION

The first data indicate a remarkable impact of the legume on animal liveweight performance (Table 3) in the nitrogen concen trations on the grass within 6 months of planting (see paper by Thomas *et al* this meeting) and in the growth of the association on the sandy soil with the higher rate of fertilizer

The conceptual outlines of the model have been sketched and guide the data being collected A prototype model of the soil system has been written and is under test We are adding a grass model animal grazing and nutrient return to address the savanna wide problem of rapid degradation of pure grass pastures The more complex aspects of a legume grass association will then be added to take account of competition population dynamics and grazing selection

This project is unique in Latin America and probably in the tropics in that it seeks to obtain mechanistic understanding of the inter relations between the components of the soil plant animal system of legume grass associations under grazing The objective of this paper is to inform colleagues of the work in progress and of the philosophy of the approach adopted

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