Compatibility, persistence and productivity of grass-legume mixtures for sustainable animal production in the Atlantic Zone of Costa Rica

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Propositions

1. The six-fold animal production increase possible as a result of the introduction of sustainable grass-legume mixtures means that the present cattle production in the Atlantic Zone of Costa Rica could be doubled by introducing such mixtures to 25% of the area.
('t Mannetje 1978, Tropical Grasslands, 12, 1-9)

2. The ability of *Arachis pintoi* to build up seed reserves in combination with its strong ability to perennate vegetatively makes this species very resilient to catastrophic events leading to a sudden set back in its growth or plant population.
This thesis

3. In the humid tropics of Costa Rica, sustainable improved pastures based on grass-legume mixtures are capable of maintaining organic carbon sinks at similar levels to that found under primary forest.
This thesis

4. Longer-lived *Stylosanthes* populations would have more chance of an adequate build up of seed reserves, which is important to ensure seedling recruitment.
This thesis

5. Early screening of legume cultivars for grazing tolerance is essential before they are released.
This thesis

6. With present market prices for non-livestock agricultural commodities being low, sustainable pasture improvement, along the lines advocated in this study, will make cattle production even more competitive with other agricultural sectors in the Atlantic Zone of Costa Rica.
This thesis

7. The dominant feature of cattle production systems on deforested areas in the humid tropics of Latin America is pasture degradation, which is the main factor contributing to the low biological and economic efficiency of extensive and semi-extensive cattle production in these regions.

8. Lack of financial resources, inadequate research capacity (quantitative and qualitative) and reduced real salary levels have made scientific and technological development in developing countries difficult.

9. Sustainable agriculture involves less use of off-farm inputs while introducing new management and cropping systems that better utilize on- farm resources.

10. Survival of an agricultural civilization depends upon its ability to retain soil fertility at a level which enables continuous productivity of sufficient land to meet subsistence needs for food and clothing. Sustainable growth of such civilization depends upon continual improvement of soil fertility.

11. Every new source from which man has increased his power on earth has been used to diminish the prospects of his successor. All his progress is being made at the expense of damage to the environment, which he cannot repair and cannot foresee.

Muhammad Ibrahim
Compatibility, persistence and productivity of grass-legume mixtures for sustainable animal production in the Atlantic Zone of Costa Rica.
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ABSTRACT

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The main objective of this study was to identify compatible and persistent grass-legume mixtures of high feeding value for forage improvement in the Atlantic Zone of Costa Rica. The study was conducted between September 1989 and October 1992 at Los Diamantes research station, Guápiles, Costa Rica. The treatments consisted of a factorial of three legumes (*Centrosema macrocarpum(Cm)* CIAT 5713, *Stylosanthes guianensis (Sg)* CIAT 184 and *Arachis pintoi (Ap)* CIAT 17434), two grasses (*Brachiaria brizantha (Bb)* CIAT 6780 and *Brachiaria humidicola (Bh)* CIAT 6339) and two stocking rates (1.75 (LSR) and 3.00 (HSR) AU/ha). Measurements were made on dry matter yields and botanical composition, legume persistence, nutritive value, liveweight gain (LWG) and soil fertility, carbon storage and soil compaction.

Dry matter yields were high in all mixtures in particular at the LSR and with *Bb*. *Cm* and *Sg* failed to persist during the 2.5 years of grazing while *Ap* was persistent, especially at the HSR. *Ap* proved to be too aggressive for *Bh*. *Ap* was more or less stable with *Bb* and it performed better at the HSR. *Bh* mixtures were invaded with unpalatable weeds while those of *Bb* were practically weed free.

Nutritive value of the mixtures was adequate for high beef production. LWG on *Bb* + *Ap* at the HSR was 937 kg/ha/year which was six times that reported for native pastures in the region and 459 kg higher than that of the monoculture of *Bb*.

Soil organic matter and total organic carbon were similar to those measured under primary forest and there was no evidence of high degree of soil compaction. From the results it is concluded that *Ap* was the most persistent legume studied and the mixture of *Bb* + *Ap* at the HSR was the most suitable combination for forage improvement in this region.

Key words: *Brachiaria brizantha*, *Brachiaria humidicola*, *Arachis pintoi*, *Centrosema macrocarpum*, *Stylosanthes guianensis*, stocking rate, dry matter yield, botanical composition, crude protein, *in vitro* dry matter digestibility, diet selection, liveweight gain, soil organic matter, soil compaction.

PREFACE

The technology of grass-legume mixtures has been very successful in Australia. Although the benefits of grass-legume mixtures are known, it has not been commercialised in Costa Rica. Over the past eight years Professor L.'t Mannetje has been actively involved in adapting this technology to Costa Rica. Through his efforts it was possible to obtain funds to do research on grass-legume mixtures in the Atlantic Zone of Costa Rica in order to increase our knowledge on the behaviour of grass-legume mixtures and the results are reported in this thesis. I am greatly indebted to him, because without his contribution this research would not have been possible. It was a privilege to work with Professor L. 't Mannetje who is a leading world authority and a pioneering researcher and educator in grassland science

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Muhammad

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CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

1. GENERAL INTRODUCTION

Introduction

Deforestation of large areas in the humid tropics has been a polemic subject in the past years, especially because of its implication related to the preservation of natural resources and the release of carbon dioxide (CO_2) and other 'greenhouse' gases to the atmosphere through the destruction of the vegetation and the loss of soil organic matter.

Reports from different countries in Latin America indicate that about 30 million hectares of humid tropical forest have been directly or indirectly converted to pasture (INPE, 1990; Peralta and Ramos, 1988; Ramirez and Seré, 1988; Salinas, 1987). This represents about 4% of the total humid tropical forests in Latin America (Serrão, 1991). In the Atlantic Zone of Costa Rica, which comprises about 570,000 ha, large scale deforestation took place from around the beginning of the twentieth century and by 1986 nearly 54% was cleared. Of the deforested area most of the land (about 60%) is occupied by grasslands, although only 25% was classified as 'pasture land' by Huising (1993). However, much of the 'wooded area' (27%) and 'grass vegetation of lands inundated or poorly drained' (7%) is also in use as grassland (Huising, 1993). The most important economic activity in the Atlantic Zone of Costa Rica is banana production, which occupies only 10% of the area. Cattle production is the second most important agricultural activity. Whereas the banana industry is for 80% foreign owned, the cattle industry is wholly Costa Rican owned and operated. Animal production is, however, being practised on a very extensive scale, with low levels of inputs and management. About 77% of the total area under pasture is dominated by very unproductive naturalised and native grasses, the main species being ratana grass (*Ischaemum ciliare*), carpet grass (*Axonopus compressus*), *Brachiaria radicans* and *Paspalum* spp. (Table 1.1.). This is common for the degraded pastures in Latin America (Toledo and Morales, 1979; Salinas, 1987; Toledo and Mendoza, 1989). The remainder of the grasslands consists of improved or selected sown grasses, of which the main ones are African stargrass, locally known as 'estrella' (*Cynodon nlemfuensis*) (14%), *Brachiaria* spp. (6%) and 'jaragua' (*Hyparrhenia rufa*) (3%) (SEPSA-CNP, 1990). These species are more frequently cultivated on dairy farms with some N fertilization.

The use of pasture legumes is virtually unknown although there is great diversity of herbaceous (*Centrosema, Pueraria* and *Desmodium* spp.) and shrub (*Cajanus cajan*) and tree

Table 1.1. Distribution of grasses in the Atlantic zone of Costa Rica

Grasses	Area (ha)	%
Natural	117,030	35.7
Ischaemum ciliare	88,510	27.0
Other grasses	46,877	14.3
Cynodon nlemfuensis	44,583	13.6
Brachiaria spp.	21,308	6.5
Hyparrhenia rufa	9,506	2.9

Source: SEPSA-CNP (1990)

legumes (*Erythrina berteroana, Gliricidia sepium* etc.) in the Atlantic Zone with a high feeding value.

The dominant feature of the pastures which are established after forest clearing in the humid tropics of Latin America generally, is pasture degradation which is the main factor contributing to the low biological and economic efficiency of the production system (Serrão, 1991). Of the approximately 8 million hectares of established pastures in the Amazon region, 30% is considered to be in an advanced state of degradation and 50% is in the process of degradation (Salinas, 1987; Schaus, 1988; Serrão, 1991). Pasture degradation is not only restricted to Latin America, but was also reported in other humid areas including north eastern Australia and Africa (Skovlin and Williamson, 1978; Gonzalez Padilla, 1980; 't Mannetje, 1982).

The process of pasture degradation was formulated by Toledo and Ara (1977), Alvim (1978) and Serrão et al. (1979). These authors highlighted that the use of species with high nutritional requirements such as: *Axonopus scoparius, Digitaria decumbens, Hyparrhenia rufa* and *Panicum maximum,* low soil fertility, particularly N and P deficiencies, without adequate if any fertilization, have been responsible for the loss of pasture productivity. The lack of forage species adapted to the prevailing soil conditions and susceptibility to pest and diseases by the grasses used, has lead to a dominance of weeds in the pastures. This is often seen as the main cause of pasture degradation. However, high weed infestation is a consequence of low productivity and lack of competitive ability of the established forage species (Salinas 1987) and an indication of poor management ('t Mannetje, 1991).

Establishment and maintenance of productive pastures in Latin America is a challenge because the majority of tropical rainforests are located on infertile soils. However, this is not the case in the Atlantic Zone of Costa Rica, with mostly Andosols and Inceptisols of medium to high fertility (Veldkamp, 1993). These young volcanic soils are rich in nutrients, generally with a neutral pH, although many areas are very stony as a result of lava and lahar deposits. Older volcanic soils are less fertile and more acid. Many areas suffer from poor drainage as a result of their topography (Alvim, 1979).

Animal production (meat and milk) in the Atlantic zone has not grown at the same rate at which the area for pastures has increased. This is largely associated with the low animal productivity from extensive and semi-extensive production systems (French, 1991). Liveweight gains from unimproved pastures in this region is only 150 to 200 g/day and animals take up to 4 years to reach marketable weight (400 kg). Average carrying capacity of existing pastures in this area is less than 1.3 adult units (AU)/ha, and total liveweight gain from native grasses seldom exceeds 200 kg/ha (CATIE, 1990). Gutierrez (1983), reported a liveweight gain of 158 kg/ha/annum at a stocking rate of 1.7 an/ha.

Milk yields from dual purpose cows is about 3 kg/day, and milk production per hectare varies between 500 to 1500 kg/ha (Vaccaro, 1989). Low milk yields from dual purpose systems is mainly caused by the poor nutrition from the pastures, but there is also a lack of genetic improvement and poor animal health and management. In the Atlantic zone, optimum climatic conditions (temperature, rainfall and humidity) exist for the reproduction and dissemination of parasites, in particular ticks and screwworms. Heavy animal losses from parasite infestations are evident in this region. The poor level of nutrition from pastures is also reflected in the low reproductive indices shown in Table 1.2. It is important to note that age at first calving is 34 months and calving interval is about 410 days, both of which have severe consequences on animal production. Experience with Zebu type cattle under grazing in other environments in the tropics showed that age at first calving was reduced significantly when animals grazed improved pastures (Coates and 't Mannetje, 1990).

The low economic efficiency of cattle rearing has several implications in the land use system in the Atlantic zone of Costa Rica. If there is not an improvement in the level of land use and production per animal, the only way to increase production in the future will be to increase the land area under pastures. This will be in competition with other agricultural activities (banana and non traditional crops), which potentially have a better profitability so that the small and marginal animal producers will have serious conflicts in the use of

Table 1.2. Productive and reproductive indices of cattle on farms surveyed in the Pococi and Cariari regions in Costa Rica.

Parameter	[1]Pococi	[2]Cariari
Stocking rate, AU/ha	1.7	1.7
Liveweight gain/ha/yr, kg	158.0	NA
Milk/cow/day, kg	3.0	5.2
Milk/cow/yr, kg	636.0	1076.0
Milk/ha/yr, kg	1081.0	1829.0
Lactation length, days	212	207
Age at first calving, months	34.8	NA
Calving interval, days	412.0	410.0

NA = Not available
Source: [1]Gutiérrez, 1983; [2]CATIE, 1990.

agricultural resources (French, 1991). Economic analysis on cattle farms in the Pococi district revealed that gross returns per unit area from the agricultural sector was 1.2 to 6.6 times higher than that obtained from beef and milk (CATIE, 1990).

In order to improve the productivity of the cattle industry there is an immediate need to improve the production of quantity and quality of forage. The species which dominate the pastures at present are not capable of higher productivity by improved management (Henzell and 't Mannetje, 1980) and although many of the soils are of medium to high fertility, they lack available nitrogen for adequate growth of quality pastures. Thus there is a need for better grasses and legumes to provide low cost nitrogen input to the pasture system as well as for protein supplementation in the animals' diet.

Higher pasture production as a result of using more productive pasture species will also lead to greater carbon fixation and reduce the net carbon loss from the soils after deforestation (Veldkamp, 1993). It can also be argued that more intensive animal production from pastures will require less land. Therefore, land which is not necessary for pastures can be reverted to forest or used for other agricultural purposes.

Up to the mid 1980's, however, there was little emphasis on pasture research and transfer of appropriate technologies to farmers. Before the activities of the International Center for Tropical Agriculture (CIAT, Colombia) in Costa Rica in 1984, the range of improved grasses and legumes being evaluated was rather small. Apart from the lack of pasture research, availability of cheap forage seed and low cost methods of pasture establishment were also seriously limiting pasture improvement in this region. Besides, the number of trained personnel in pasture agronomy is very limited and there is a need to increase the knowledge of technicians in this field.

Studies by the Research and Education Centre for Tropical Agriculture (CATIE), the Ministry of Agriculture and Animal Production (MAG), CIAT and the joint research programme of the Agricultural University of Wageningen with CATIE and MAG have shown that the humid, warm climate and the generally fertile volcanic soils are very well suited for pasture production, provided productive species, including pasture legumes are used (Ibrahim et al., 1993). The use of grass-legume mixtures is recommended for sustainable improved animal production in the region. In small plot cutting studies by CIAT (Vallejos, 1988; Roig, 1989) a number of grasses and legumes has been found to be adapted to the climate and soil of at least part of the Atlantic Zone of Costa Rica. However the performance of legume-grass mixtures under grazing conditions has not been extensively evaluated. One of the main problems of grass-legume mixtures in the tropics is the lack of persistence of legumes, particularly under heavy grazing. This is because of the use of the wrong species, overgrazing or lack of proper plant nutrition. The choice of species needs to take into account adaptation to the local environment, pest and disease tolerance and ability to tolerate defoliation, particularly by grazing.

Practical technologies for pasture improvement in the Atlantic Zone of Costa Rica

The philosophy of low input technology for pasture improvement is a relatively new strategy for improving animal production in developing tropical countries. The main objective is to increase animal production in a profitable manner, without suffering unfavourable social and ecological consequences.

Available technology and its application

Research by various institutions (e.g. CSIRO in Australia, CIAT in Colombia, EMBRAPA in Brazil and ILCA in Ethiopia) has resulted in the release of a wide range of new forage species and cultivars for the diverse tropical ecosystems (Henzell and 't Mannetje, 1980; 't Mannetje, 1984; 't Mannetje and Jones, 1992).

For the humid Atlantic Zone in Costa Rica grasses belonging to the genus *Brachiaria*, in particular *B. humidicola* (Schultze-Kraft and Teitzel, 1992), *B. dictyoneura* (Schultze-Kraft, 1992a), and *B. brizantha* (Schultze-Kraft, 1992b) are the most suitable for the well drained infertile soils, whereas grasses like *Panicum maximum* (Chen and Hutton, 1992) and *Cynodon nlemfuensis* (Hanna, 1992) prefer better soil fertility (CIAT, 1989, 1990; 't Mannetje, 1990). Apart from grasses various herbaceous legumes have been selected for the humid tropical environment including *Stylosanthes guianensis* ('t Mannetje, 1992), *Centrosema macrocarpum*, (Schultze-Kraft, 1992c), *C. acutifolium* (Schultze-Kraft, 1992d), *Desmodium heterocarpon* ssp. *ovalifolium* (Schulze-Kraft, 1992e) and *Arachis pintoi* (Cook, 1992) (CIAT, 1989; Toledo and Mendoza, 1989; CIAT, 1990).

In selecting new herbage species, emphasis is being placed on the adaptation of plants to the soil constraints rather than the elimination of all soil constraints to meet the plant requirements. The grass species *Andropogon gayanus* and *Brachiaria humidicola* and the legume species *Stylosanthes capitata, S. guianensis* and *Arachis pintoi* (Salinas and Delgadillo, 1980; CIAT, 1980; Sanchez and Salinas, 1981; CIAT, 1989, 1990) are capable of thriving on soils with low available phosphorous (3.4 to 5 ppm (Olsen)). However with some legumes small doses of phosphorus, sulphur and molybdenum may be necessary to stimulate vigorous legume and rhizobium growth depending on soil ferility (Hutton, 1979).

Not only has there been a breakthrough in identifying potential species for pasture improvement, but also the knowledge of grazing management and herbivore nutrition has been broadened. Experience with erect grasses (*Panicum maximum*, *Pennisetum purpureum*, *Hyparrhenia rufa* etc.) (Sierra Posada, 1980; Avendaño et al., 1986; Ibrahim, 1990) and twining legumes (*Centrosema macrocarpum*, *Pueraria phaseoloides*, *Neonotonia wightii* etc.) (Davison and Brown, 1985; Jones and Clements, 1987; Hurtado, 1988; Ibrahim et al., 1993) proved that they are very susceptible to grazing and therefore conservative stocking rates are required for their persistence.

As a result of a better understanding of grazing ecology, pastures can be managed to increase production, efficiency of pasture utilisation and persistence of pasture species (Cubillos, 1974; Stobbs, 1978; Cowan et al., 1986). In the Atlantic Zone of Costa Rica sustainable forage improvement can be undertaken using selected improved grasses and legumes either 1) by establishing pure grass pastures with NPK fertilization, 2) by sowing grass-legume mixtures, 3) by oversowing legumes into existing pastures, 4) by establishing protein banks and 5) by establishing fodder crops ('t Mannetje, 1990). Which of these methods of pasture

Table 1.3. Annual liveweight gain per ha from various pasture types grazed at different stocking rates (animals (An)/ha).

Pastures	Years of grazing	Stocking rate (An/ha)	Liveweight gain, kg/ha/yr
Native Pastures			
Homolepis aturensis[a]	1	1.5	110
Paspalum notatum[b]	1	3.1	20
Improved grasses			
Brachiaria humidicola[c]	2	2.5	351
Andropogon gayanus[c]	2	2.1	340
Legume-based pastures			
Andropogon gayanus + *Centrosema macrocarpum*[d]	5	4.4	660
Andropogon gayanus + *Stylosanthes guianensis*[e]	2	3.5	650
Brachiaria decumbens + *Desmodium ovalifolium*[e]	5	5.5	897
Brachiaria dictyoneura + *Desmodium ovalifolium*[d]	4	5.0	803

Source : [a]Caquetá, Colombia (Maldonado, 1990). [b]Cauca, Colombia (Escobar et al., 1971). [c]Paragominas, Brazil (EMBRAPA, 1988). [d]Quilichao, Colombia (CIAT, 1989). [e]Yurimaguas, Perú (Dextre et al., 1987)

improvement is selected depends on several factors including the intensity and objective of production. Intensive grassland management with the use of NPK fertilizers in the Atlantic Zone is not recommended for extensive and semi-extensive (dual purpose) cattle production owing to the low economic efficiency of these systems and unstable prices paid for beef. For these production systems legumes have an important role for forage improvement because of their high nutritive value and ability to fix nitrogen from the atmosphere (Henzell et al., 1966; Vallis, 1972; 't Mannetje, 1982; Vallis, 1983). Under humid tropical environments established grass/legume mixtures are capable of producing between 500 and 700 kg liveweight gain per hectare and this is two to three times greater than the levels reported from unimproved native pastures in the wet tropics (Table 1.3.). With legume-based pastures improved cattle production is not only a function of better animal productivity, but it is also related to increased carrying capacity resulting from high dry matter yields ('t Mannetje, 1982; Humphreys, 1991). In the Atlantic Zone, well managed grass/legume mixtures can support 2.5 to 3 AU/ha (Hurtado, 1988) depending on the soil type, and this represents a remarkable improvement when it is considered that the average stocking rate is only 1.1 AU/ha for existing pastures in the region (SESPA-CNP, 1990). Apart from legumes being involved in improving animal production, there are also additional benefits of legumes including improvement of soil fertility (Vallis, 1985).

Objectives

The main problem to be studied was that of legume persistence and grass-legume compatibility in a grazing situation. Legume and grass growth habit and grazing pressure are very important factors in the productivity and sustainability of grass-legume mixtures.

Therefore, the reaction of grass-legume mixtures to grazing pressure, as caused by stocking rate, must be known and understood. The nutritive value of new pasture species or cultivars is also important to assess the net productivity of the pastures. In the case of more intensive forms of animal production, such as dairying, the nutritive value of forage is important to calculate rations. The type of research reported in this thesis can also be seen as the final evaluation of new pasture species before their release to farmers. Frequently new grass and legume species or cultivars are recommended to farmers before any information is available about their persistence in mixtures with grasses and the optimum management. Grazing and where necessary amendments to soil fertility are the main management tools a farmer has available to manipulate the productivity and longevity of the pasture.

Outline of the thesis

The main body of the thesis consists of research findings from an experiment carried out at the Los Diamantes Experimental Station of MAG at Guápiles in the Atlantic Zone of Costa Rica. This experiment was established in 1989 to investigate the persistence of legumes when grown with different grass species under grazing at a medium and a heavy stocking rate. The three legumes and two grass species selected for the experiment differed in growth habit, which, together with the two stocking rates, provided twelve situations to study the problem of legume persistence and grass-legume compatibility. In addition, the nutritive value of the grass-legume combinations was studied in terms of crude protein and *in vitro* digestibility, and diet selection by cattle. Furthermore, changes in soil nitrogen and carbon content as well as in bulk density were studied.

In a supplementary experiment animal production of the most successful grass-legume combination was investigated.

The agronomic significance of the findings and the applicability of the results are discussed in the final chapter.

CHAPTER 2

PRODUCTIVITY AND COMPATIBILITY OF PASTURE GRASSES AND LEGUMES IN THE ATLANTIC ZONE OF COSTA RICA

2. PRODUCTIVITY AND COMPATIBILITY OF PASTURE GRASSES AND LEGUMES IN THE ATLANTIC ZONE OF COSTA RICA.

Introduction

Establishment of legume-based pastures in the humid tropics offers a good alternative for sustainable forage production ('t Mannetje and Jones, 1990; 't Mannetje, 1991; Toledo and Formoso, 1993). Some of the major difficulties in promoting legume-grass pastures in the region have been to find legumes which are not only adapted to environmental conditions but are compatible with aggressive grass species and are able to withstand heavy grazing. Commercial species of *Brachiaria*, in particular *B. decumbens* and *B. humidicola* are vigorous, strongly tillering grasses which tend to suppress most associated legumes in time (McIvor, 1978; Grof, 1985; Kretschmer, 1985; Schultze-Kraft and Teitzel, 1992 a,b).

In the humid tropics conditions of rainfall and temperature favour vigorous growth of the high yielding C_4 grasses. Maximum tropical legume growth usually occurs during hot periods when tropical grass growth is at a maximum. Competition of the grass for space, light, moisture and soil nutrients sometimes makes it difficult to establish and maintain tropical legumes in the pasture and special management may be required to maintain persistent legume yield (Kretschmer, 1985). However, it should be indicated that many tropical legume cultivars from species of genera such as *Desmodium* and *Stylosanthes*, which are grazing tolerant, have been developed under adverse conditions of grass competition (Schulze-Kraft and Giacometti, 1979). The level of stocking rate fixed is considered important for sustainable legume yield. Experience in humid environments showed that the twining (eg. *Centrosema pubescens, Neonotina wightii, Pueraria phaseloides*) and erect (eg. *Stylosanthes guianensis*) tropical pasture legumes rarely persist under year-round stocking rates exceeding 2.5 beasts/ha (Humphreys, 1980; Davison and Brown, 1985; Jones and Clements, 1987). Farmers are unlikely to accept such low stocking rates because of the investments incurred for establishing legume mixtures. Therefore, genetic and managerial strategies should be developed to allow higher levels of pasture productivity. Superior performance of legumes used in the humid zone is necessary if farmers are to continue establishing them.

Agronomic studies conducted by the CIAT Pasture program in the Atlantic Zone of Costa Rica have identified various legumes and grasses with good potential for pasture improvement on moderately to well drained soils (Vallejos, 1988; Roig, 1989; CIAT, 1990).

However, the performance of these species in legume-grass associations under grazing has not been extensively evaluated. Hence the main objective of this study was to identify compatible grass/legume mixtures for the humid tropics of Costa Rica. This chapter reports results on dry matter yield and botanical composition of the legume mixtures as well as data on total above ground nitrogen yield of some of the legume-grass mixtures.

Materials and methods

Location

The experiment was conducted between September 1989 and November 1992 at the "Los Diamantes" research station at Guápiles (10° 13' Lat. N, 83° 47' Long. W, Alt. 250 m) in the Atlantic Zone of Costa Rica. Mean annual rainfall of the area is 4332 mm, which is well distributed throughout the year, except for a short drier period between the months of December and April. The mean temperature is 24.6 °C with relatively small diurnal and annual variation. The soil of the experimental site is a well drained loamy Eutric Hapludand or Umbric Andosol, of medium to high fertility (Wielemaker and Oosterom, 1990). Soil pH (H_20) varies between 5.7 to 5.9 and available phosphorus (Olsen) between 6 and 8 ppm. The soils of 'Los Diamantes' have no known problems of trace element deficiencies for legume and grass growth.

Treatments

The treatments consisted of a factorial (3×2×2) of three legumes of contrasting growth habit (*Centrosema macrocarpum (Cm)* CIAT 5713, *Stylosanthes guianensis* (*Sg*) CIAT 184 and *Arachis pintoi* (*Ap*) CIAT 17434), two grasses of different morphology (*Brachiaria brizantha* (*Bb*) CIAT 6780 and *B. humidicola* (*Bh*) CIAT 6339), and two stocking rates (1.75 (LSR) and 3.0 (HSR) AU/ha) both of which are higher than the average stocking rate (SR) of the region. The species have been described in 't Mannetje and Jones (1992). Stocking rates were fixed by adjusting the plot size (0.066 ha (HSR) and 0.114 ha (LSR)), and the treatments were randomly assigned to plots. There were two replicates for each treatment.

Pasture establishment and grazing

The grass-legume mixtures were established during September 1989. Intensive cultivation was necessary since the land was previously dominated with a dense vegetation of the weed

Paspalum fasciculatum also known as "gamalote" in Costa Rica. The grasses were established vegetatively (1.5 tons/ha) on a 1.0 x 0.5m grid. The legumes *Sg* and *Cm* were sown in between the grasses, at a seeding rate of 3 and 5 kg/ha, respectively, whilst *Ap* was planted vegetatively by working 1 ton/ha of stolons into the soil between grass rows. All species in the experiment established well, except for *Sg* which was replanted in January and February, 1990. At planting 15 kg P/ha was applied as triple super, but no further fertilizer application was made during the experiment.

Grazing was initiated in January 1990 to achieve uniformity of the plots and to establish the grazing cycles. Data collection for yield and composition was started in May 1990 for *Ap* and *Cm* mixtures, while that of *Sg* associations began in July 1990 because of slow establishment. The mixtures were grazed with steers of the Ministry of Agriculture weighing between 250 and 320 kg. Initially, the grazing cycle was fixed with a resting period of 24 days and 4 days grazing, but this was extended to 35 days (30 days resting and 5 days grazing), because of the poor recovery of the species.

Measurements

Botanical composition and forage dry matter yield on offer was measured before each grazing cycle. Botanical composition was determined by the dry weight rank method ('t Mannetje and Haydock, 1963; Jones and Hargreaves, 1979), taking 60 samples per plot. Forage dry matter yield (DM) on offer was estimated with the comparative yield method developed by Haydock and Shaw (1975). Residual DM after grazing was measured similarly to estimate DM production assuming linear growth rates during the grazing period. From this annual DM production was calculated.

With *Cm* and *Ap* mixtures, total plant material of the sown grass and legume and volunteer species were sampled frequently to determine N concentration (Kjeldahl). N yield was calculated as the product of DM yield and N concentration.

Statistical analysis

The data on available DM yield and botanical composition were analysed for a split plot design. The treatments were assigned to main plots and grazing cycles to sub-plots.
An analysis of variance was made to test homogeneity of variance of grazing cycles. Least significant difference (LSD) and Duncan's multiple range test were used to test differences between treatment means.

Results

Dry matter yield

Available dry matter yields. The mean total DM yields at the beginning of each grazing cycle over SR's and legume spp. was above 4 ton/ha in all grazing months and there were some seasonal variations of DM availability (Fig. 2.1.). DM yields decreased significantly ($P < 0.01$) in the short dry period between November and April, whereas maximum yields

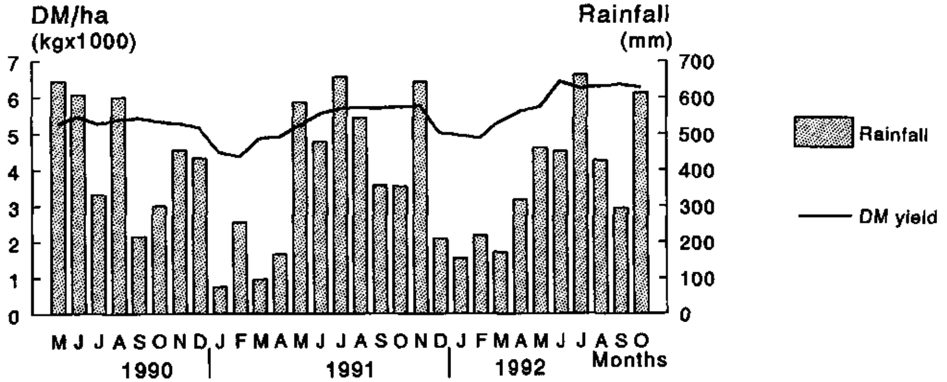

Fig. 2.1. Seasonal variation of mean available DM yield (kg/ha) of the grass-legume mixtures grazed at two stocking rates in relation to rainfall.

occured between the months of May and November when rainfall was high. However, there was not a high correlation between DM yields and rainfall ($r = 0.51$). In the first grazing year there was a steep decline in the amount of total DM on offer of *Sg* in the *Bh* treatments between August and November (1990) (Fig. 2.2.). This coincided with profused flowering of the legume.

Mean total DM yields of the treatments, at the beginning of each grazing cycle, are shown in Table 2.1. DM yields were significantly ($P < 0.001$) lower at 3.00 than at 1.75 AU/ha and *Bb* had significantly ($P < 0.001$) higher DM yields than *Bh*. Legume species had no significant effect on total DM yields with *Bb* mixtures but with *Bh* the DM yields were lower for *Cm* than for the other legumes. DM yields in the first grazing year showed an increasing trend with time except for *Bh* with *Ap* at the HSR which showed a depression in DM yield in the second grazing year. However in the last six grazing months available DM yield of

Table 2.1. Mean total dry matter yields (ton/ha) at the beginning of each grazing cycle in the mixtures *Bb+Ap*, *Bh+Ap*, *Bb+Cm*, *Bh+Cm*, *Bb+Sg* and *Bh+Sg* grazed at two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha).

	LSR		HSR		Mean for Legume
	Bb	*Bh*	*Bb*	*Bh*	
		ton DM/ha			
+ *A. pintoi*					
[1]May 90 - Oct 90	6.9	6.2	4.7	4.2	
Nov 90 - Apr 91	6.3	5.5	4.2	3.6	
May 91 - Oct 91	7.6	5.6	5.2	3.4	
Nov 91 - Apr 92	6.8	5.3	4.7	3.0	
May 92 - Oct 92	7.5	7.0	5.3	6.9	
Mean	7.0	5.9	4.8	4.2	5.5
+ *C. macrocarpum*					
[1]May 90 - Oct 90	7.0	4.3	5.1	3.4	
Nov 90 - Apr 91	6.3	3.8	4.6	3.0	
May 91 - Oct 91	7.8	5.5	5.5	3.9	
Nov 91 - Apr 92	7.1	5.0	5.3	3.5	
May 92 - Oct 92	7.8	5.9	5.6	4.1	
Mean	7.2	4.9	5.2	3.6	5.2
+ *S. guianensis*					
[2]July 90 - Oct 90	7.1	4.6	5.2	3.9	
Nov 90 - Apr 91	6.4	4.3	4.5	3.7	
May 91 - Oct 91	7.7	6.0	5.7	4.4	
Nov 91 - Apr 92	6.9	5.7	5.2	3.9	
May 92 - Oct 92	7.8	6.7	5.6	4.6	
Mean	7.2	5.5	5.2	4.1	5.5
Mean of SR ($LSD_{.05}$= 1.6)		6.3		4.5	
Mean of grasses over SR and legumes: *B. brizantha* 6.1 *B. humidicola* 4.7					

Bh+Ap at the HSR had increased by 130%. This was due to a sudden increase in the presence of *Paspalum fasciculatum* (Table 2.3.)

Annual dry matter yields

Mean annual DM yield of the pasture components are presented in Table 2.2. Total DM yield averaged 22.5 tons/ha over treatments. SR had the greatest effect on total DM yield, that at the LSR being 54% higher than that at the HSR which was significant ($P < 0.01$). Total DM of *Bb* was higher than that of *Bh*, and with *Bb* there was no significant effect of legume species on total annual DM yield. With *Bh*, the mean total DM yield of *Cm* was lower ($P < 0.01$) than that of *Ap* and *Sg*. *Ap* made a substantial contribution to annual DM yields with *Bh* under both SR and with *Bb* at the HSR (Table 2.2.). In general DM yields of *Cm* and *Sg* were low except for *Sg* with *Bh*. In associations with *Bh*, volunteer species made a significant contribution to total DM yield in particular with *Cm*.

Botanical composition

Between April 1990 and November 1992 significant changes ($P < 0.001$) were detected in the botanical composition of DM on offer. The mean percentage of sown grass, legume and volunteer species at the beginning of each grazing cycle is given in Table 2.3.

The sown grasses differed in persistence. *Bb* maintained high dry weight percentages in all treatments, but *Bh* began to be replaced by volunteer species, mainly *P. fasciculatum* and *Mimosa pudica*, after the first year. The persistence of the legumes also differed markedly and this was affected by associated grass species as well as by SR. *Cm* and *Sg* only performed well in the first year in association with *Bh*. *Cm* had virtually disappeared by the second year in all treatments, whilst *Sg* persisted to some extent only with *Bh* at the LSR.

At the end of grazing *Cm* and *Sg* represented less than 5% of total pasture on offer (Fig. 2.2.). In contrast, *Ap* was persistent at the HSR, but in the second grazing year there was a dramatic increase in the amount of *Ap* in *Bh* swards to such an extent that it represented more than 70% of forage on offer under the high SR. On the other hand, *Ap* was more or less stable with the erect *Bb* and with this grass it maintained a favourable composition (> 20%) at the HSR (Fig. 2.2.).

Nitrogen yield

The results of total above ground N yield measured from *Cm* and *Ap* mixtures in the 2½ years of grazing is shown in Table 2.4. Total N yield of *Ap* mixtures was significantly ($P < 0.01$) higher than that of Cm mixtures. *Ap* accounted for a significant percentage of total above ground N yield especially with *Bh* and with *Bb* at the HSR (Fig. 2.3.). There was a high correlation between above ground N yield of *Ap* and the percentage of *Ap* in the mixtures ($r = 0.98$). The contribution of *Cm* to total N yield was insignificant with *Bb*, while with *Bh* the contribution of *Cm* to N yield was only important in the first grazing year (Fig. 2.3.).

Table 2.2. Mean annual dry matter yield (ton DM/ha) of the sown grass and legume and volunteer spp. estimated from Bh and Bb associations with *Ap*, *Cm* and *Sg* grazed at two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha).

	LSR		HSR		Mean of total
	Bb	*Bh*	*Bb*	*Bh*	
+ *Arachis pintoi*		ton DM/ha			
Sown grass	25.7	16.2	15.6	6.0	
Sown legume	2.7	5.6	4.9	6.8	
Volunteer spp.	0.9	4.6	1.2	5.0	
Total	29.3	26.4	21.7	17.8	23.8a
+ *Centrosema macrocarpum*					
Sown grass	27.1	2.1	18.5	5.7	
Sown legume	0.3	1.8	0.4	1.8	
Volunteer spp.	2.6	15.6	1.1	7.9	
Total	30.0	19.5	20.0	15.4	21.2a
+ *Stylosanthes guianensis*					
Sown grass	28.0	16.5	17.7	12.4	
Sown legume	0.4	4.8	0.5	1.6	
Volunteer spp.	0.9	3.8	1.4	1.6	
Total	29.3	25.1	19.6	15.6	22.4a

Mean total DM of SR over grasses and legumes (ton/ha)		Mean total DM of grasses over legumes and SR (ton/ha)	
LSR	26.6	*Bb*	25.0
HSR	18.3	*Bh*	20.0

Table 2.3. Mean dry weight percentage of sown grass (G%) and legume (L%) grown in association and volunteer species (V%) at the beginning of each grazing cycle at two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha).

	LSR						HSR					
	B. brizantha			*B. humidicola*			*B. brizantha*			*B. humidicola*		
	G%	L%	V%	G%	L%	V%	G%	L%	V%	G%	L%	V%
+ *A. pintoi*												
May 90 - Apr 91	84.9	12.3	2.8	87.9	10.8	1.3	80.4	16.5	3.1	76.1	20.7	3.2
May 91 - Apr 92	88.1	9.1	2.8	59.9	30.4	9.7	74.7	18.4	6.9	28.1	58.4	13.5
May 92 - Oct 92	81.8	10.9	7.3	36.3	19.4	44.3	62.3	25.1	12.6	4.7	20.2	75.1
Mean	84.9	10.8	4.3	61.4	20.2	18.4	72.5	20.0	7.5	36.3	33.1	30.6
+ *C. macrocarpum*												
May 90 - Apr 91	94.6	1.5	3.9	26.1	28.8	45.1	92.1	3.6	4.3	37.4	31.7	30.9
May 91 - Apr 92	88.9	0.3	10.8	4.8	1.1	94.1	92.7	1.1	6.2	37.3	2.6	60.1
May 92 - Oct 92	83.9	0.2	15.9	2.6	0.3	97.1	92.7	0.4	6.9	30.7	1.7	67.6
Mean	89.1	0.7	10.2	11.2	10.1	78.8	92.5	1.7	5.8	35.1	12.0	52.9
+ *S. guianensis*												
July 90 - Apr 91	92.1	5.7	2.2	54.9	38.3	6.8	87.2	8.1	4.7	69.7	25.2	5.1
May 91 - Apr 92	96.8	0.1	3.1	69.8	10.4	19.8	91.5	0.3	8.2	73.0	3.5	23.5
May 92 - Oct 92	97.8	0.1	2.1	64.6	4.3	31.1	90.8	0.2	9.0	58.7	1.5	39.8
Mean	95.6	2.0	2.5	63.1	17.7	19.2	89.8	2.9	7.3	67.1	10.1	22.8

Mean of SR over grasses and legumes	G%	L%	V%	Mean of grasses over SR and legumes	G%	L%	V%
LSR	67.5	10.2	22.2	*B. brizantha*	87.4	6.3	6.3
HSR	65.5	13.3	21.1	*B. humidicola*	45.7	17.2	37.1

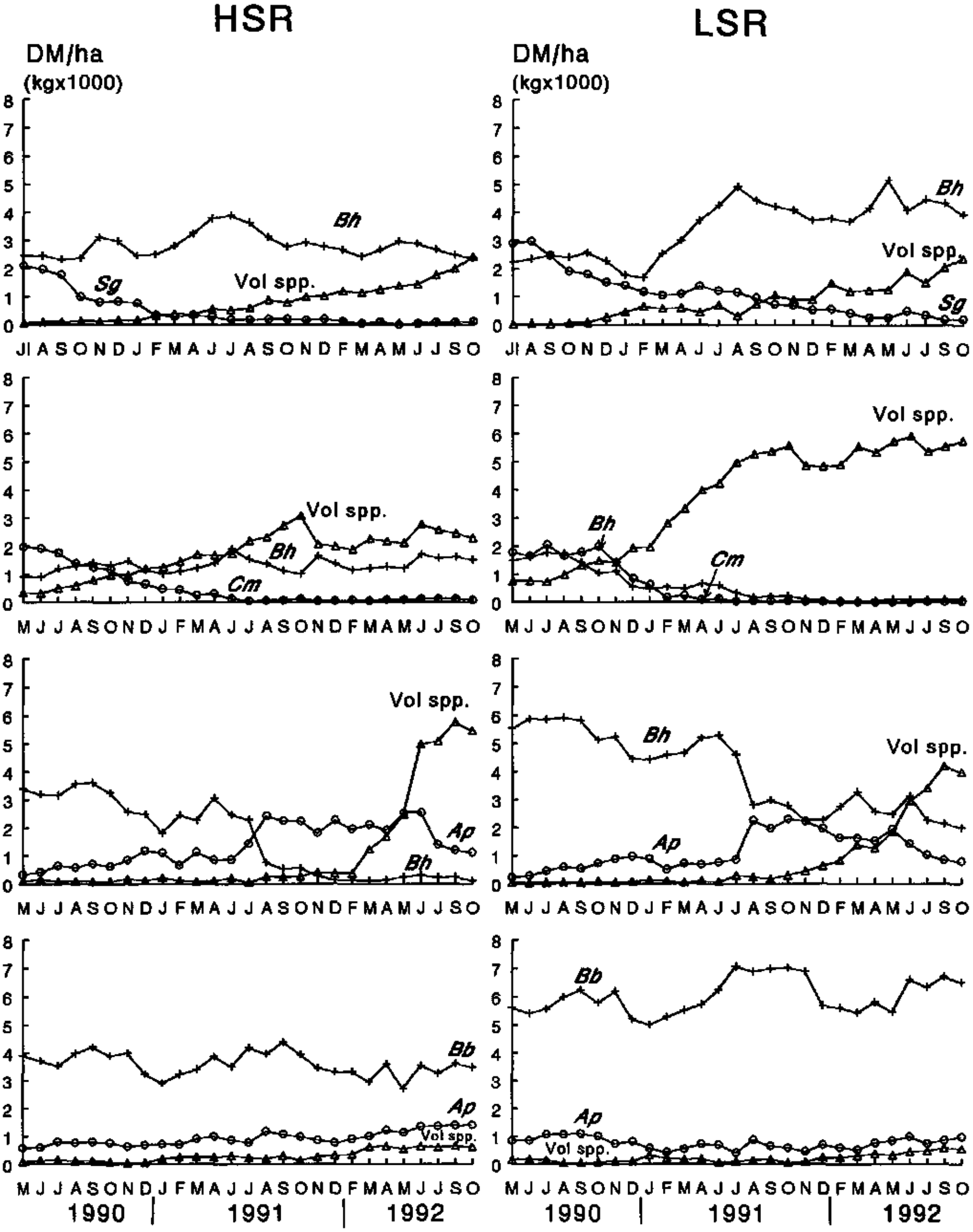

Fig. 2.2. The effect of stocking rate (HSR = 3.00 AU/ha, LSR = 1.75 AU/ha) on the DM yield of species in the mixtures of *A. pintoi* (*Ap*), *S. guianensis* (*Sg*) and *C. macrocarpum* (*Cm*), with *B. humidicola* (*Bh*) and of *A. pintoi* grown with *B. brizantha* (*Bb*).

Table 2.4. Total above ground N yields measured over a 2½ year grazing period from *Cm* and *Ap* mixtures grazed at two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha).

Mixture	LSR	HSR	Mean
		kg N/ha	
Bb+Cm	678	559	618a[1]
Bh+Cm	702	579	640a
Bb+Ap	874	911	892b
Bh+Ap	1007	911	959b
Mean of SR	815	740	

[1]values within the same column with different letters are significantly different ($P < 0.05$) according to Duncan ranking.

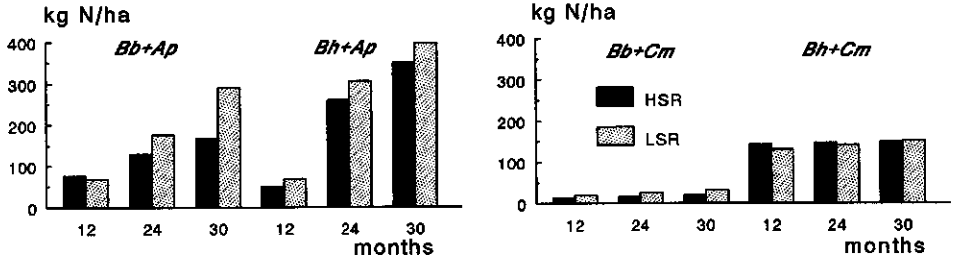

Fig. 2.3. Cumulative above ground N yield of *A. pintoi* (*Ap*) and *C. macrocarpum* (*Cm*) estimated in mixtures with *B. brizantha* (*Bb*) and *B. humidicola* (*Bh*) grazed at two stocking rates (HSR = 3.00 AU/ha, LSR = 1.75 AU/ha) at intervals after the start of grazing.

Discussion

In general legumes established better with the more stoloniferous *Bh* than with the tufted *Bb*. This is contrary to what might be expected from results reported from the literature which showed that legumes were more compatible with tufted grasses (Wong and 't Mannetje, 1981; Toledo and Fisher, 1990). But it should be mentioned that the *Bh* accesssion (CIAT 6369) used in this experiment is less aggressive compared to other *Brachiaria* cultivars (Grof, 1982; Vallejos, 1988). Apparently lodged tillers of *Bb* suppressed growth of *Cm* and *Sg* in the establishment phase by limiting the amount of light, while *Ap* survived, because of its ability to tolerate shading (Ng, 1991). The results of this and another grazing experiment in Brazil (Spain et al., 1993) showed that there was difficulty in establishing some legumes with *B. brizantha*. Spain et al. noted that legumes including *Stylosanthes capitata* and *C. macrocarpum* represented 30 to 60% of the total forage on offer in association with *Panicum maximum* cv. Vencedor, while legume content was less than 5% in mixtures with *B. brizantha*.

Ap was very tolerant to heavy grazing, which is consistent with the findings of Hernandez et al. (Chapter 6 of this thesis) in another experiment with *Bb* at "Los Diamantes" experimental Station. *Ap* is one of the tropical legumes that can withstand heavy grazing (Hurtado, 1988; Argel, 1993). It has a very prostrate growth habit and a dense mat of stolons, which ensure protection of a high percentage of growing points from defoliation (Grof, 1985; Argel, 1993). A rapid decline in the contribution of *Sg* and *Cm* suggests that both SR's were too high for these legumes. The failure of these legumes to persist for more than two years conforms with general experience in Brazil, Perú and Colombia (Grof, 1986; Serrão, et al., 1990; Lascano and Avilla, 1991). These species are generally grazing intolerant since *Cm* has twining stems with buds readily accessible to the grazing animal and *Sg* has erect shoots branching from the main stem which also makes it vulnerable to heavy grazing (Thomas et al., 1985).

The sudden dominance of *Ap* over *Bh* corresponded with a period of excessive rainfall and this presumably created stress conditions for growth of the grass. Moreover *Ap* is known to be very aggressive under wet conditions (Roig, 1989; Cook et al., 1990) and it can even withstand flooding for short durations (CIAT, 1986).

Ap resulted in a good mixture with *Bb* under heavy grazing and the results of this experiment are indicative of the need for selection of appropriate companion grass species for this legume as well as appropriate grazing management. *Ap* was very competitive for the prostrate *Bh* and the same has been reported for the creeping African star grass (*Cynodon nlemfluensis*) in Costa Rica at Turrialba (Heurck, 1990) and with other *Brachiaria* spp. like *B. dictyoneura* and *B. ruziziensis* grazed in the wet zone of Colombia (Grof, 1985).

DM yields over the last six grazing months coincided with the high rainfall season, and this partially explains a significant increase in mean DM yields in this period. Low DM yields observed with *Bb* in the first year may be attributed to frequent grazings at the beginning of the experiment. Agronomic studies showed that *Bb* was very susceptible to frequent defoliations (CATIE, 1989, 1990), which may be related to a rapid decline in soluble carbohydrates following cutting or grazing (White, 1973). On the other hand a sharp increase in available DM yields of *Bh* mixtures in the second and third year can be associated to a shift in species composition in the pasture towards a greater percentage of volunteer grasses.

Bh pastures were degraded in time with the invasion of the highly stoloniferous *Paspalum fasciculatum* which has a good tolerance for wet conditions (Ibrahim, 1990; Martinez et al., 1993a). This weed is very unpalatable (Martinez et al., 1993b) and this is perhaps one of the main reasons for its rapid propagation in the pastures. It is interesting to note that although *Ap* tended to being a monoculture under heavy grazing with *Bh* it was subsequently also invaded by *P. fasciculatum*. In monoculture *Ap* is very prostrate and it can be easily invaded by weeds (Dwyer et al., 1990), but in competition with grasses *Ap* has been observed to be more vigorous (Ayarza et al., 1993) growing up to 50 cm in height (Ibrahim, unpublished data).

Bb sustained high DM yields, whereas *Cm* and *Sg* disappeared in a short time and this may be related to the soils being fertile at the experimental site. Results from other long term studies showed that yields of *B. decumbens* monoculture declined in time whereas in association with *Pueraria phaseloides* it sustained high yields (CIAT, 1986; Toledo, 1991; Toledo and Formoso, 1993) and this is also expected with *Bb* + *Ap* mixtures grazed over a longer period. In this experiment *Bb* had more than 4 tons DM/ha available before each grazing cycle in association with *Ap* at HSR, which is in close agreement with the data of Hernandez et al. (Chapter 6. in this thesis).

Total above ground N yields were very high reaching up to 907 kg/ha. This may be related to high DM yields which varied between 15.4 and 30 tons/ha depending on grass species and SR (Table 2.2.). Over the 2½ years of grazing the above ground N yield of *Ap* was between 290 to 398 kg /ha with *Bb* at the HSR and with *Bh* at both SR, and this is equivalent to an annual N yield of 116 to 159 kg/ha. These values are superior to that reported for tropical legumes grown in mixtures elsewhere. Seiffert et al. (1985) in Brazil noted that *Calopogonium mucunoides* grazed at 2.5 AU/ha contributed 87 kg N/ha/yr to total N yield when in mixture with *Brachiaria decumbens*. In Queensland, Australia, Johansen and Kerridge (1979) reported that *Macroptilum atropurpureum* cv. Siratro, *Lotononis bainesii* cv. Miles and *Desmodium intortum* cv. Greenleaf yielded between 63 to 85 kg N/ha annually in mixtures with *Panicum maximum* cv. Gatton. In this experiment *Ap* produced more than 5 tons DM/ha/yr which explains the high N yield of this legume.

CHAPTER 3

PERSISTENCE OF *Centrosema macrocarpum*, *Stylosanthes guianensis* AND *Arachis pintoi* IN ASSOCIATION WITH TWO *Brachiaria spp.* GRAZED AT TWO STOCKING RATES IN THE ATLANTIC ZONE OF COSTA RICA

3. PERSISTENCE OF *Centrosema macrocarpum*, *Stylosanthes guianensis* AND *Arachis pintoi* IN ASSOCIATION WITH TWO *Brachiaria spp.* GRAZED AT TWO STOCKING RATES IN THE ATLANTIC ZONE OF COSTA RICA.

Introduction

Low input tropical pasture technology has been developed for the humid and subhumid tropics and subtropics, including Central and Latin America. However there have been disappointments in the persistence of some grass-legume mixtures, which has largely been due to the failure of the legume species to persist for more than 3 to 5 years under heavy grazing.

The persistence of plants is a function of (1) the longevity of originally established plants, (2) plant replacement through the processes of flowering, seed formation, accretion to soil seed reserves, seedling regeneration, and seedling survival to flowering, or (3) plant replacement from perennating vegetative buds (Humphreys, 1991; 't Mannetje, 1991).

The optimum seed bank for plant replacement contains (1) sufficient germinable, soft seed to give emergence upon any rainfall event favourable for successful seedling regeneration and (2) sufficient density of long-lived seeds to maintain seed reserves at satisfactory levels if replenishment is interrupted by adverse climatic or other environmental and management factors. Stocking rate exerts the primary control of the level of seed reserves, but this may depend on palatability of the species.

Longevity is firstly a character under genetic control. Many perennial tropical herbage legume prove to be quite short lived as individuals (Gardener, 1981; Jones and Bunch, 1988a, 1988b). Long-lived plants that occupy the same site for a number of years are more resistant to weed invasion than short-lived plants and are more resilient under a range of grazing managements.

A successful legume therefore has to be able to withstand inter-plant competition and defoliation and must be tolerant of the prevailing diseases and pests. Variation in grazing intensity can markedly affect legume longevity (Leach, 1978), seed set (Taylor and Rossiter, 1974; Jones and Jones, 1978), seed ingestion (Playne, 1974; Jones 1989; Gardener et al., 1993), seedling regeneration (Jones and Mott, 1980) and seedling survival (Jones, 1973). Knowledge of the population dynamics of the species concerned is therefore important in the selection of the correct managerial practices for maintaining a persistent pasture and it can provide a basis for selecting new genotypes better fitted to the environment and the management practices employed.

The experiment reported in this chapter provided the opportunity to study the persistence of three legumes adapted to this environment and soil type with two adapted grass species at two stocking rates.

Materials and methods

In Chapter 2 the geographic location, the climate and soil under which the study was carried out, as well as pasture establishment, treatments and lay-out of the experiment were described. It concerned a factorial combination of the legumes *Centrosema macrocarpum (Cm), Stylosanthes guianensis (Sg)* and *Arachis pintoi (Ap),* with the grasses *Brachiaria brizantha (Bb)* and *Brachiaria humidicola (Bh).* The treatments were rotationally grazed at a low (LSR = 1.75 AU/ha) and a high stocking rate (HSR = 3.00 AU/ha). There were two replicates of each treatment. Persistence mechanisms of the legume species were measured between October 1989 and October 1992.

Measurements

Flowering. Flowering was observed in 45 quadrats of 0.25 m^2 (0.5 X 0.5 m) per plot. *Ap* flowered year-round and the density of flowers was measured every month. *Sg* flowered only in early September and counts were made of the number of reproductive units (flowers + pods)/m^2 at peak flowering time. *Cm* did not flower at all in the grazed plots, which was due to defoliation, as flowers were observed on plants out of the reach of animals.

Seed reserves. Seed reserves were only measured for *Sg* in *Bh* swards and for *Ap* with both grasses at the two SR's. This measurement was taken every six months for *Ap* (October 1990, April and October 1991, April and October 1992) and one to two months after flowering for *Sg* (November 1990, November 1991 and October 1992). Forty cores of 7 cm diameter were taken from each paddock at a sampling depth of 5 cm for *Sg* and 15 cm for *Ap*. The cores were bulked into five samples of 10 cores, each sample being taken over the whole pasture using stratified random sampling. Seeds of *Sg* were extracted from the bulked soil samples by the method described by Jones and Bunch (1977), whilst *Ap* seeds were recovered from the soil by simply washing through a sieve.

Plant density. The density of legume plants and of newly emerged seedlings was measured in quadrats of 0.5 m^2 (1 X 0.5 m) for *Sg* and *Cm* and of 0.06 m^2 (0.25 X 0.25 m) for *Ap* taking 30 samples in each paddock. *Ap* develops underground shoots (Cook et al., 1990; Dwyer et al., 1990) and therefore it was impossible to count individual crowns without destructive sampling. Consequently a plant was defined as a single shoot coming through the ground. The legume plants were counted every six months starting from April 1990. Seedling counts were also recorded every six months and this commenced in October 1990 for *Ap* and in April 1991 for *Sg* seedlings.

Survival rates. In each plot 100 legume seedlings were tagged four weeks after emergence in 1989 with a plastic covered wire. These plants were counted every three months to determine survival rates. Survival rate of newly emerged seedlings were also determined using tags of different colours for each new cohort.

Plant regeneration. In April 1990 thirty-five fixed quadrats of 1 by 0.5 m were pegged out randomly in *Cm* treatments. In each quadrat the stolons just above on or under the soil were carefully traced and measured in June 1990, January 1991 and June 1991. The stolon length was rated for diameter size (class 1: 1-5 mm and class 2: 5-10 mm). The number of rooted stolons was also counted on the same dates with stolon measurements. After June 1991, these measurements were not carried out because *Cm* had disappeared in all treatments.

For *Ap* all stolons on or within 2.5 cm of the soil surface were included in the cores taken for soil seed reserve in October of 1990, 1991 and 1992. On these dates stolon lengths were measured and the number of rooted points were counted. A rooted point was defined as where one or more roots originated from a stolon regardless of root sizes. At the October 1991 and October 1992 samplings, the proportion of rooted points that had one or more roots > 1 mm diameter as well as the number of roots between 1-4 mm, 4-10 mm and > 10 mm diameter were also recorded. The root diameters were measured close to the parent stolon. At the last measurement, roots were separated into primary taproots or secondary adventitious roots with respect to their point of origin.

Results

Cm did not flower within the experimental plots, but only when it grew on trees adjacent to the experiment. On the other hand *Sg* disappeared in *Bb* treatments in a short time after grazing. Therefore, in terms of flowering, seed reserves and seedling recruitment, it is only possible to present data on *Ap* with all treatments and *Sg* only in the *Bh* association at both SR's.

Flowering and seed reserves

Flowering. The total number of reproductive units/m^2 recorded for *Sg* in *Bh* treatments at peak flowering in each year and the number of flowers/m^2 recorded for *Ap* throughout the year with *Bb* and *Bh* at the two SR's are presented in Fig. 3.1. *Sg* flowered early in

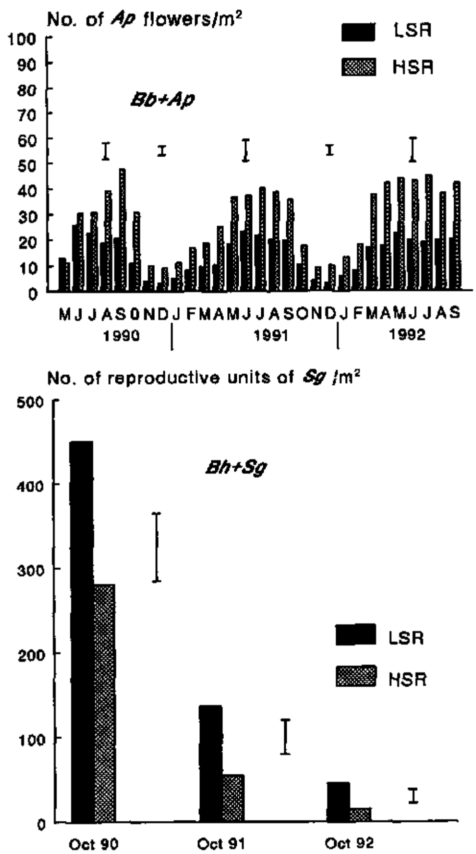

Fig. 3.1. The effect of stocking rate (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha) and grass species (*Brachiaria brizantha* (*Bb*) and *Brachiaria humidicola* (*Bh*)) on the number of flowers/m^2 of *A. pintoi* (*Ap*) and of stocking rate on the number of flowers and pods/m^2 of *S. guianensis* (Sg) with *B. humidicola*. Vertical bars indicate LSD (P = 0.05)

September whilst *Ap* flowered all year round with a steep decline ($P < 0.01$) in the number of flowers/m^2 between November and February. At all counting dates the number of reproductive units/m^2 of *Sg* was significantly ($P < 0.001$) higher at the LSR than at the HSR, but it was drastically reduced in time. Combining the data from both SR's in all measurements, there was a significant ($P < 0.001$) linear relationship between the number of reproductive units/m^2 of *Sg* (F) in October of each year and presentation yields (Fig. 2.2.) of *Sg* (Y) in the corresponding period ($F = -3.9 + 0.26Y$, $r^2 = 0.98$).

The density of *Ap* flowers was significantly ($P < 0.001$) different between grass species and SR's, but in all treatments the mean flowering density/year of *Ap* was considered adequate for seed production. The variation in the number of *Ap* flowers/m^2 with the two grasses and SR's was strongly related to differences in the dry weight percentage of *Ap* between treatments (Table 2.3.). A sharp increase in the number of *Ap* flowers/m^2 in the *Bh* treatments in the second grazing year coincided with the sudden increase in the amount of *Ap* in the corresponding period (Fig. 2.2.).

Soil seed reserves. The changes in soil seed reserves of *Sg* in *Bh* swards and of *Ap* with both grasses at the two SR's over time are illustrated in Fig. 3.2. At each sampling date the standard error of the mean of the 5 samples from each pasture was usually 12 to 23% of the mean for *Sg* and 7 to 19% of the mean of *Ap*. Seed reserves of *Ap* increased in time, but it was significantly ($P < 0.001$) affected by grass species and SR. The levels of seed reserve was always much higher under the HSR, and in the *Bh* associations. Combining the data for both SR's, the linear regression of seed reserves against time showed that *Ap* seed reserves increased at a rate of 35 and 65 seeds/m^2/month in *Bb* and *Bh* pastures respectively. Similarly, the linear regression detected a significantly ($P < 0.01$) higher rate of increase in *Ap* seed reserves at the HSR than at the LSR.

In contrast, there was a linear rate of decline in *Sg* seed reserve with time and on all sampling dates seed reserves of *Sg* were consistently higher ($P < 0.001$) at the LSR. Pooling the data from the two SR's, a good relationship was found when the number of reproductive units/m^2 (R) of *Sg* in each year (Fig. 3.1.) was plotted against seed reserves (S) measured in the same period ($S = -126.2 + 0.52R$, $r^2 = 0.85$).

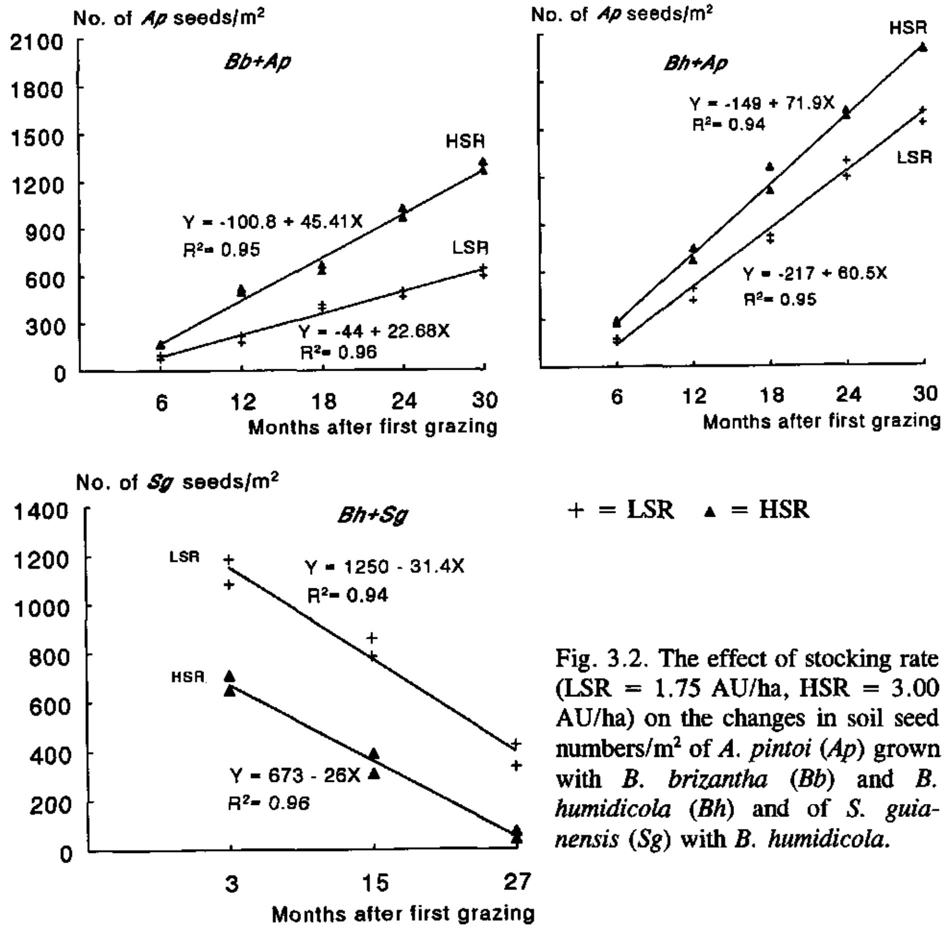

Fig. 3.2. The effect of stocking rate (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha) on the changes in soil seed numbers/m² of *A. pintoi* (*Ap*) grown with *B. brizantha* (*Bb*) and *B. humidicola* (*Bh*) and of *S. guianensis* (*Sg*) with *B. humidicola*.

Survival rate

Original plants. The longevity of tagged legume plants of each species which emerged from initial sowings was analysed by plotting legume death percentage against time in months since emergence. A non-linear regression analysis was performed to describe the relationship since death rates were not constant in time, and the curves were fitted with the model $f(Y) = A / [1 + B * \exp^{(C*x)}]$, where x is months after emergence and C estimates death rate. The results in Fig. 3.3. showed that the model was very efficient to estimate % mortality of the legume species. There was no significant effect of SR on longevity of the legumes, except for *Sg* which had a higher death rate at the HSR than at the LSR in association with *Bh*.

The legumes tended to be shorter-lived when grown with *Bb* than with *Bh*, in particular *Sg*.

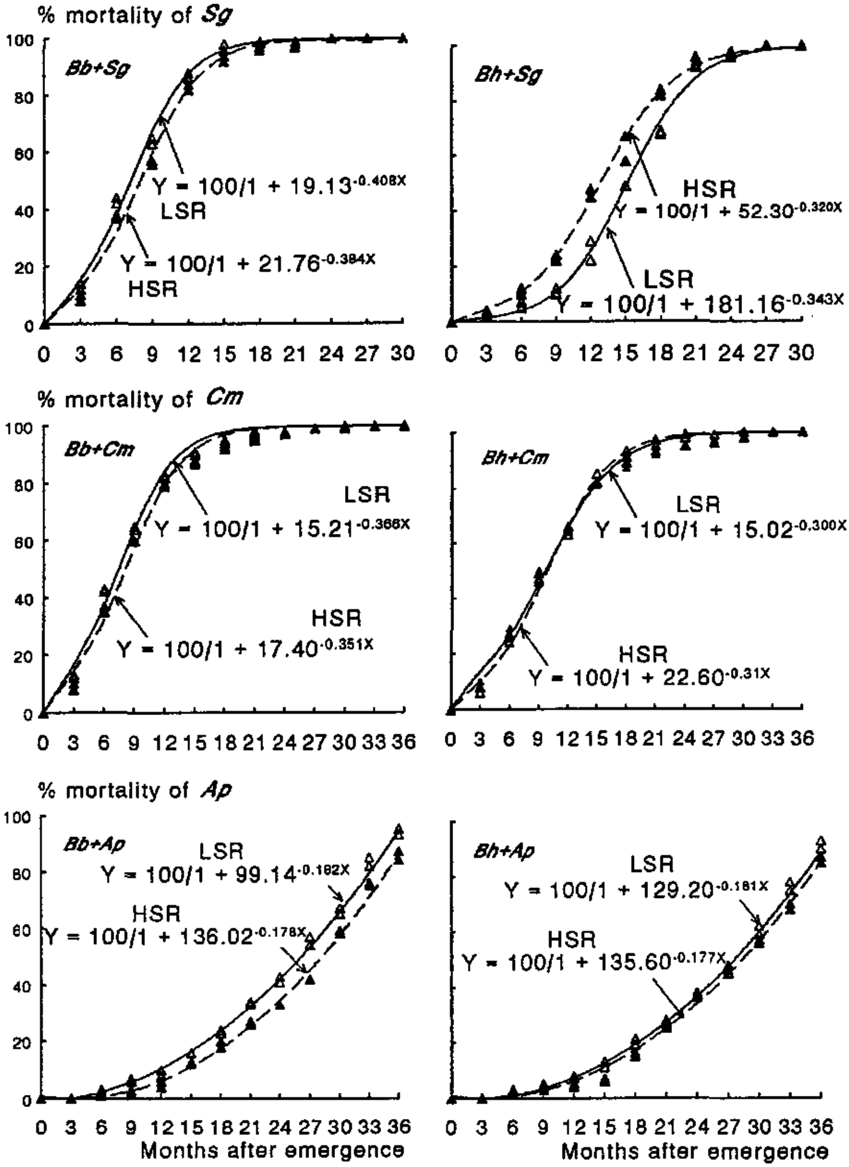

Fig. 3.3. The effect of stocking rate (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha) and grass species (*Brachiaria brizantha* (*Bb*) and *Brachiaria humidicola* (*Bh*)) on the percentage mortality of *S. guianensis* (*Sg*), *C. macrocarpum* (*Cm*) and *A. pintoi* (*Ap*) measured over three years (△ = LSR and ▲ = HSR, data of replicates).

Eighteen months after emergence an average over SR of 24.5 *Sg* plants/m^2 was still surviving in *Bh* mixtures, whereas this was only 2.5 *Sg* plants/m^2 with *Bb* in the same period. The percentage survival of marked plants of *Cm* and *Sg* was lower than for *Ap*. The half life of the legumes, averaged over grasses and SR's, was 8.0, 10.2 and 26.7 months respectively for *Cm*, *Sg* and *Ap*. There was a marked increase in the death rate of legumes six months after emergence which was more pronounced for *Cm* and *Sg* than for *Ap* (Fig. 3.3.).

Seedlings. The percentage of *Ap* and *Sg* seedlings surviving from March 1991 until September 1992 is given in Table 3.1. The seedlings were shorter lived than the parent population, but the percentage of *Ap* seedlings surviving was significantly ($P < 0.001$) higher than that of *Sg*. Between 20 and 36% of *Ap* plants were still surviving 18 months after emergence depending on grass species and SR, whilst all tagged *Sg* seedlings had died. The death rate of *Sg* seedlings was not affected by SR. At the LSR death rate of *Ap* was similar for *Bb* and *Bh* mixtures, but at the HSR, there was a lower death rate of *Ap* seedlings for the *Bb* association. The linear regression coefficient for percentage seedling survival against time accounted for between 83 and 98% of the variance in the relationship. With *Bh*+*Ap* the regression accounted for a lower proportion of the variance because of a faster rate of decline at the end of the cohort's life span than was allowed for in the linear regression. It should be indicated that high mortality of *Ap* plants in the *Bh* association over the last three months coincided with a strong invasion of weeds (Chapter 2).

Plant and seedling density

Plant density. The effect of grazing on the density of legumes with both grasses in time are described in Fig. 3.4. At the beginning of the experiment there were considerably fewer *Cm* and *Sg* than *Ap* plants in *Bb* treatments and this was related to poorer establishment of these legumes as discussed in Chapter 2. In time there was a run down in plant densities of *Cm* and *Sg* in all treatments. SR had little effect on the densities of these two legumes, except with *Sg* in the *Bh* association. On all sampling dates the number of *Sg* plants in the *Bh* mixture was always higher ($P < 0.01$) at the LSR. Contrary to this, plant densities of *Ap* in April 1990 had significantly ($P < 0.001$) increased and there were significant effects ($P < 0.01$) of grass species and SR on the number of *Ap* plants counted. The mean number of *Ap* plants/m^2 was higher for the HSR than for the LSR and in association with *Bh*.

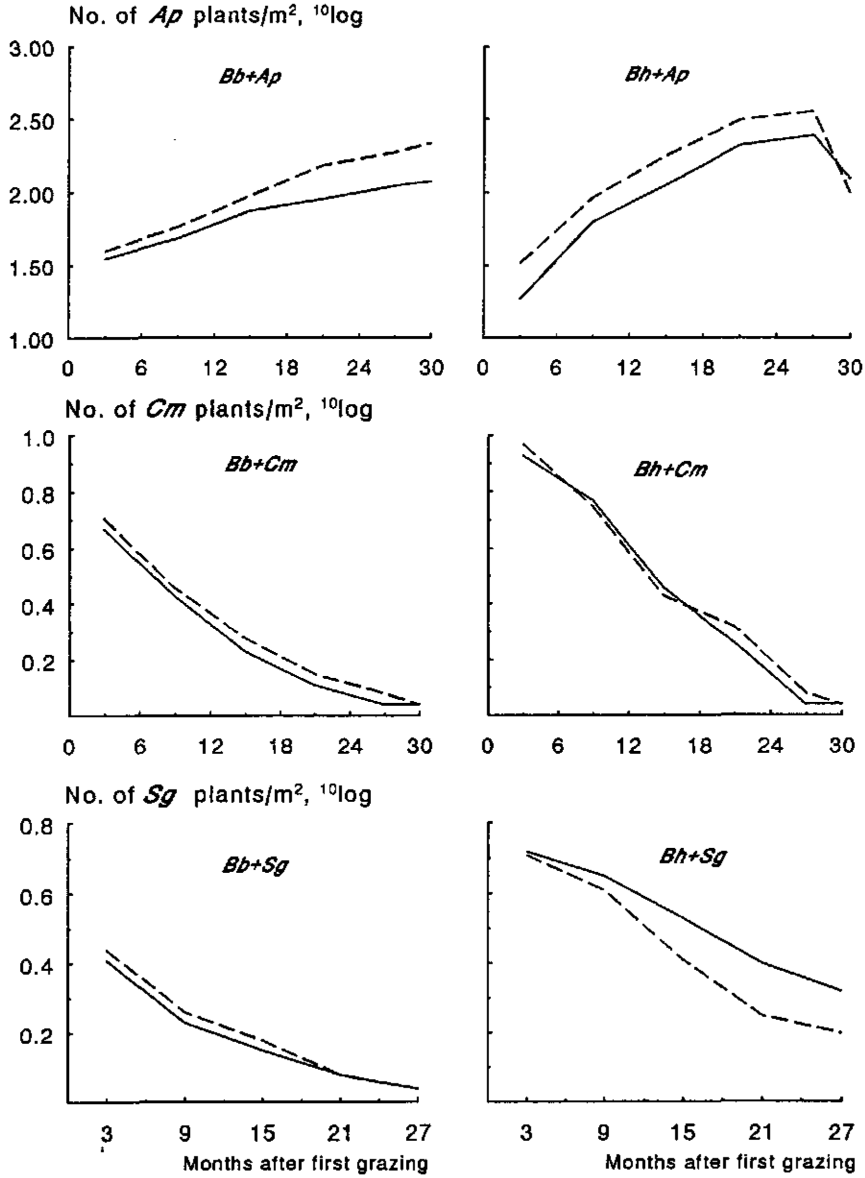

Fig. 3.4 Changes with time in plant densities (^{10}log) of *A. pintoi (Ap)*, *C. macrocarpum* (*Cm*) and *S. guianensis* (*Sg*) in association with *B. brizantha* (*Bb*) and *B. humidicola* (*Bh*) grazed at two stocking rates (------ = HSR (3.00 AU/ha) ——— = LSR (1.75 AU/ha)).

Table 3.1. The percentage (%) of *A. pintoi* and *S. guianensis* seedling surviving in time with *B. humidicola* (*Bh*) and *B. brizantha* (*Bb*) grazed at two stocking rates (HSR, LSR).

	Arachis pintoi (%)				*S. guianensis* (%)	
	HSR		LSR		HSR	LSR
	Bb	*Bh*	*Bb*	*Bh*	*Bh*	*Bh*
Months						
3*	95.5	96.5	98.0	96.5	81.0	83.2
6	86.0	89.0	91.0	85.5	58.2	61.2
9	74.0	79.0	80.0	74.3	38.2	42.3
12	59.0	66.0	64.5	64.3	17.3	21.3
15	43.5	51.0	51.0	48.2	1.1	3.2
18	28.0	23.2	35.3	20.1	0.0	0.0
Regression analysis						
b	-4.10	-4.10	-3.70	-4.30	-6.00	-5.90
r^2	0.97	0.84	0.95	0.85	0.96	0.97

* = March '91 HSR = 3.00 AU/ha LSR = 1.75 AU/ha

In mixture with *Bh* there was a marked increase in the density of *Ap* plants in the second grazing year, but in the last six grazing months, the number of *Ap* plants/m^2 in this mixture declined sharply, with the invasion of weeds.

Seedlings. The results on the number of seedlings per m^2 in time for *Ap* in all treatments and of *Sg* with *Bh* at the two SR's are shown in Table 3.2. Pooling the untransformed data over SR for the *Bb* mixture, the regression analysis detected a significant linear rate ($P < 0.01$) of increase in seedling numbers/m^2 (Y) of *Ap* with time (X,months) ($Y = 16.95 + 4.44X$, $r^2 = 0.92$). Seedling numbers of *Ap* in October 1990 had also increased in time in the *Bh* association, but between April and October 1992 there was a marked reduction in the number of *Ap* seedlings counted. The average number of *Ap* seedlings/m^2 over sampling dates was higher ($P < 0.05$) for *Bh* (169) than for *Bb* (97). Stocking rate also had a significant ($P < 0.01$) effect on the mean seedling numbers of *Ap*, that at the HSR being 38 to 126% higher than that at the LSR, depending on grass species. On the other hand there was no major event in seedling strikes of *Sg* in the duration of the experiment. The number of *Sg* seedlings/m² had decreased linearly with time. On all counting dates seedling numbers of *Sg* at the LSR was double that at the HSR, which was significant ($P < 0.01$).

Table 3.2. The effect of stocking rate (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha) on changes of seedling numbers/m² in time of *A. pintoi* with *B. humidicola* and *B. brizantha* and of *S. guianensis* with *B. humidicola*.

	B. humidicola		*B. brizantha*	
	LSR	HSR	LSR	HSR
+ *A. pintoi*				
Oct '90	32.6 (1.53)[1]	69.6 (1.85)	30.5 (1.50)	40.8 (1.62)
Apr '91	105.4 (2.03)	135.7 (2.13)	46.5 (1.68)	96.4 (1.99)
Oct '91	278.6 (2.54)	395.4 (2.60)	69.4 (1.85)	149.6 (2.18)
Apr '92	204.6 (2.31)	279.0 (2.45)	73.8 (1.87)	179.3 (2.25)
Oct '92	88.3 (1.95)	102.3 (2.01)	77.4 (1.89)	205.3 (2.31)
Mean	141.9 (2.07)	196.4 (2.21)	59.5 (1.76)	134.3 (2.07)
+ *S. guianensis*				
Apr '91	2.4 (0.53)	1.2 (0.34)	-	-
Oct '91	2.3 (0.52)	1.1 (0.32)	-	-
Apr '92	1.8 (0.45)	0.9 (0.28)	-	-
Oct '92	1.4 (0.38)	0.7 (0.23)	-	-
Mean[2] (LSD=0.10)	2.0 (0.47)	1.0 (0.29)		
Mean of *Ap* seedlings over SR and time.				
B. brizantha	96.9 (1.91)			
B. humidicola	169.1 (2.14)			
LSD (P =0.05)	(0.18)			

[1]Values in parenthesis are log (X+1) transformed data, [2]LSD at P = 0.05
- = Not measured.

Table 3.3. Changes over time in stolon length and the number of rooted stolons/m^2 of *C. macrocarpum* in association with *B. brizantha* (*Bb*) and *B. humidicola* (*Bh*) at two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha).

	LSR		HSR	
Attribute	*Bb*	*Bh*	*Bb*	*Bh*
Stolon length (m/m^2)				
June 1990	5.3	32.1	6.8	24.5
January 1991	2.2	14.3	2.7	13.8
June 1991	0.1	1.0	0.2	1.9
Stolon size (diameter)				
% stolon length 1-5 mm size	84.2	76.2	85.2	80.3
% stolon length 5-10 mm size	14.3	22.1	12.1	19.4
Rooted stolons (no./m^2)				
June 1990	20.2	121.2	18.5	85.0
January 1991	6.3	56.1	4.8	47.0
June 1991	1.0	1.6	1.1	2.1

Plant regeneration

Centrosema macrocarpum. The results of stolon and rooting characteristics of *Cm* with the grass species and at the two SR's are shown in Table 3.3. At the June 1990 measurement, the length of *Cm* stolon/m^2 in *Bh* swards was four to five times higher than that measured in *Bb* swards. With *Bh* stolon length/m^2 of *Cm* at the LSR was higher ($P < 0.05$) than that at the HSR in June 1990, but thereafter there was no significant effect of SR. As grazing progressed there was a dramatic decline in the length of *Cm* stolons/m^2, which was attributed to the decline in plant density of *Cm* with time. The linear regression coefficient of stolon length of *Cm*/m^2 (y) against plant density of *Cm* (x), accounted for between 83 to 95% of the variance in the relationship, depending on grass species and SR.

Between 75 to 86% of *Cm* stolons was within the 1-5 mm class size, and there was a higher percentage (19.4 to 22.1%) of coarse (5-10 mm) stolons in the *Bh* association. SR had no significant effect on stolon size of *Cm*. The number of rooted stolons/m^2 varied in the same way as stolon length of *Cm* did. In the *Bh* association the number of rooted stolons/m^2 averaged across SR was 28.3, 14.0 and 1.4 in June 1990, January 1991 and June 1991, respectively.

Table 3.4. Changes over time in stolon length and rooting charactersitics of *A. pintoi* grown with *B. brizantha (Bb)* and *B. humidicola (Bh)* managed at two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha).

	LSR		HSR	
Attribute	*Bb*	*Bh*	*Bb*	*Bh*
Stolon length (m/m^2)				
October 1990	24	36	33	40
October 1991	38	135	86	184
October 1992	50	70	117	78
Roots (October 1991)				
Rooted points (no./m of stolon)	45	47	46	50
1-4 mm diam. roots ($no./m^2$)	231	872	529	1154
4-10 mm diam. roots ($no./m^2$)	102	445	301	463
> 10 mm diam. roots ($no./m^2$)	10	33	30	39
Total > 1 mm diam. (no./m of stolon)	9	10	10	9
Roots (October 1992)				
Rooted points (no./m of stolon)	43	48	45	47
1-4 mm diam. roots (no/m^2)	279	420	818	491
4-10 mm diam. roots ($no./m^2$)	120	170	304	168
> 10 mm diam. roots ($no./m^2$)	12	40	48	43
Total > 1 mm diam. (no./m of stolon)	8	9	10	9
% adventitious roots > 1 mm diam.	66	63	65	69

Arachis pintoi. Table 3.4. presents data on stolon and rooting characteristics of *Ap* with the two grasses at the two SR's. The mean stolon length of *Ap* over treatments and sampling dates was 74.2 m/m^2. In mixture with *Bb* stolon length/m^2 of *Ap* in October 1990 followed an increasing trend with time, while in mixture with *Bh* it had increased dramatically between October 1990 and October 1991, but thereafter stolon length/m^2 of *Ap* decreased significantly ($P < 0.01$). The variation in stolon length of *Ap* with *Bh* in time was associated with variation in the contribution of *Ap* to this mixture. Stolon length of *Ap* averaged over sampling dates for *Bh* (90.7 m/m^2) was significantly ($P < 0.05$) higher than that of *Bb* (58 m/m^2), and that at the HSR (89.7 m/m^2) was higher than at the LSR (58.8 m/m^2).

The number of roots > 1 mm diameter /m^2 was significantly ($P < 0.01$) different between treatments and sampling dates, and this was attributed to variation of stolon length/m^2 with time. Pooling data over treatments and sampling dates, there was a high correlation ($r = 0.99$) between the total number roots > 1 mm diameter /m^2 and stolon length /m^2. The number of rooted points averaged 46/m of stolon across treatments and sampling dates, and some 8 to 10 roots/m of stolon was > 1 mm diameter. Between 60 and 71% of the roots > 1 mm in diameter was within the 1-4 mm class size whilst some 24 to 35% was within the 4-10 mm class size. Root separation in October 1992 showed that more than 60% of roots with > 1 mm diameter resulted from adventitious roots.

Discussion

Flowering and seeding

Cm did not flower in the experimental plots. The problem of flowering of *Cm* in this environment was also reported in agronomic studies with various legume species at this site by Roig (1989). This author reported that only *Centrosema arenarium* produced seeds out of the 13 *Centrosema* species evaluated. Schultze-Kraft (1987) noted that defoliation apparently had a negative effect on flowering of *Cm* and this agrees with our observation that undefoliated *Cm* plants flowered outside of experimental plots. Apart from defoliation low radiation and temperatures are also thought to affect flowering and seeding of *Cm* (Ramos-Santana and Tergas, 1990). However, these problems do not apply to this site, except for reduced radiation due to cloud cover during certain periods.

Sg flowered profusely in September but seed reserves were depleted in time which clearly demonstrates that there was a negative balance between seed input and seed losses. The decline in seed input was largely attributed to a significant reduction in the amount of *Sg* in the pastures after the first grazing year (Fig. 2.2.). This is evident from the number of reproductive units counted, which averaged 365/m^2 over SR's in October 1990, while in October 1992 it only averaged 45/m^2.

A run down of seed reserves in time was also measured with other tropical legumes including *Macroptilium atropurpureum* cv. Siratro (Jones, 1979; Jones and Bunch, 1988b), *Desmodium intortum* cv. Greenleaf (Jones, 1989) and *Centrosema virginianum* (Jones and Clements, 1987). In a thirteen year grazing experiment with *M. atropurpureum* conducted at Narayen research station, Queensland, Australia, 't Mannetje and Jones (1990) reported that seed reserves of this legume grazed at 1.1 steers/ha declined from 464 seeds/m^2 to less than 45 seeds/m^2 at the end of this period. These authors concluded that the actual disappearance of *M. atropurpureum* in the pasture was associated with depletion of seed reserves much needed for persistence of this legume under grazing.

Ap flowered all year round, but the decrease in flowering observed each year between November and February could indicate a quantitative short day effect, as rainfall was not lacking during those months. However, this phenomenon was not reported in the literature (Grof, 1985; Roig, 1989; Cook et al., 1990). Experience with *Ap* in the Llanos of Colombia showed that this legume was photoperiod neutral with a tendency for reduced flowering during heavy rainfall or moisture stress (Grof, 1985).

Seed reserves of *Ap* increased in all treatments especially when it was grazed at the HSR. This is contrary to results reported for other tropical legumes in the literature which almost exclusively show that high SR have negative effects on seed reserves. Examples of the decrease in legume seed reserves with increasing stocking rate have been published for *M. atropurpureum* (Jones and Bunch, 1988b; 't Mannetje and Jones, 1990), for *Stylosanthes* spp. (Gardener, 1978; 1981; Mott et al., 1989), for *Lotononis bainesii* (Pott and Humphreys, 1983) and for *Desmodium uncinatum* (Jones and Evans, 1977; Jones and Clements, 1987). The same was observed with *Sg* in this experiment. Dry matter yields of *Ap* were higher at the HSR than at the LSR, which explains higher seed reserves with the former.

At the end of the 2½ years of grazing seed reserves of *Ap* in association with *Bb* at the LSR (640 seeds/m^2) was lower than those of the other treatments (1265 to 2010 seeds/m^2), but the level was considered sufficient to secure seedling recruitment. Seed reserves recorded for *Ap* in this experiment overlapped with values measured for *Ap* in *Brachiaria* pastures in Colombia (Rocha et al., 1985). In another experiment with *Ap* at Samford, Queensland, Australia, Jones (1993) measured similar values of seed reserves in sown rows, but seed reserves measured across paddocks in mixtures with *Setaria sphacelata* and *Paspalum notatum* were lower than results of this experiment. This difference was presumably related to better climatic and soil conditions at Guápiles which favours good growth of *Ap* and hence prolific flowering and seed set.

Longevity and plant recruitment

Grazing had adverse effects on plant densities of *Cm* and *Sg* which fell below 1.0 plant/m^2 at the end of the 2½ years grazing period. The early run down in plant densities of *Cm* and *Sg* was a result of no or inadequate seedling recruitment in combination with the short-life span of these species. Half-life values estimated for original populations of *Cm* and *Sg* were only 7.5 to 15 months depending on grass species and SR. Similar half-life values have been reported under grazing for *Stylosanthes hamata* cv. Verano at Lansdown, Queensland, Australia (Gardener, 1978, 1980a; Mott et al., 1989), and *S. guianensis* cv. Graham and *Macrotyloma axillare* cv. Archer at Mt. Cotton, Queensland, Australia (Von Sury et al., unpublished data). However, studies realised by Mott et al. (1989) indicated higher half-life values of *Stylosanthes scabra* and *S. viscosa* (21 months) than of *Sg* in this experiment.

Survival rates of *Sg* were somewhat higher in mixture with the prostrate *Bh* than with the erect *Bb*. This may be associated to the erect growth habit adapted by *Sg* in competition with *Bb*, leading to heavy grazing of the regenerative tissues. Longevity of *Cm* was not significantly affected by grass species and in both mixtures it actually disappeared 18 months after grazing. On the other hand, a considerable percentage of original *Ap* plants survived into the third grazing year which is a good indication of the strong perenniality of this species. The 25 to 27 months half-life of the original plants of *Ap* is similar to the half-life measured under grazing for *Ap* grown on podzolic and colluvial soils at Samford, Queensland, Australia (Jones, 1993) and for *Desmodium intortum* and *D. uncinatum* at Beerwah, Queensland, Australia (Jones, 1989).

The results of Jones (1993) showed that the half-life of *Ap* was only 4 months on poorly drained alluvial soils indicating the need for good site selection for the establishment of *Ap*. The number of *Ap* seedlings in October 1990 had increased significantly ($P < 0.01$) in all treatments and this was reflected in increased plant densities of *Ap* over the 2½ years of grazing. *Ap* seedling numbers counted in this experiment were comparable to those counted in mixtures with *Bh* ($145/m^2$) and *B. dictyoneura* ($128/m^2$) grazed over two years in the Llanos of Colombia, but higher than that ($26.6/m^2$) counted for *Ap* at Samford, Queensland, Australia (Jones, 1993). In the last six grazing months there was a sharp decrease in seedling and plant densities of *Ap* in mixture with *Bh*. This was presumably associated to increased seedling mortality of *Ap* because of the light competition from the vigorous *P. fasciculatum*, which dominated the *Bh* mixture at the end of grazing (Chapter 2). With increased competition light may limit legume growth leading to mortality and this is supported by results of Jones and Bunch (1988b), which related high seedling death of *M. atropurpureum* to low light levels. In another study Grant (1975) found that increased weed competition resulted in higher death rates of *M. atropurpureum* in the absence of weed competition.

Seedling and plant density of *Ap* were greater for the HSR than for the LSR, which is not in keeping with the results cited for the majority of tropical legumes in the literature. Population studies with *M. atropurpureum* (Jones and Bunch 1988a, 1988b) and *Centrosema virginianum* (Jones and Clements, 1987) showed negative effects of increasing SR on plant densities. Studies realised by Jones (1979) at Samford, Queensland, Australia showed that plant density of *M. atropurpureum* at low stocking rate (1.3 steers/ha) was 7.1/m^2 while at high SR (2.8 steers/ha) it was only 3.3/m^2. In this experiment *Ap* maintained higher dry weight percentages in the mixtures at the HSR than at the LSR and this may explain a higher seedling density at the HSR, since there was higher seed input at the HSR.

In contrast, seedling numbers of *Sg* were never above 2.4/m^2 on any counting date. Seed reserves measured in October 1990 were less than 1500 seeds/m^2 and this was considered inadequate to guarantee optimum seedling replacement. According to plant population studies conducted by Gardener (1981) with *S. hamata* at Townsville, Queensland, Australia, an average seed bank of 6900 seed/m^2 was adequate for plant replacement. In this experiment only about 1% of total *Sg* seed lost from the pool was accounted for in seedling replacement. The results from other experiments indicated that some 8-10% of seed reserves of *S. hamata* (Gardener, 1981) and *Medicago truncatula* (Carter, 1983) was accounted for by seedlings. These observations show that large, seemingly wasteful, seed production is necessary for persistence of herbaceous legumes in grazed pastures. *S. guianensis* is among one of the most persistent *Stylosanthes* spp. and the reason for the poor persistence of this species is unaccountable. Demographic studies conducted by Mott et al. (1989) showed that the species *S. scabra* and *S. viscosa* persisted for more than 4-years under grazing in native pastures. In general *Stylosanthes* spp. are well adapted to very poor soils. It is possible that the good soil conditions at Los Diamantes did not favour *Sg*. This is supported by results of Amezquita et al. (1991) which showed that this cultivar of *Stylosanthes* (*S. guianensis* cv. Pucallpa) was most suited for acid soils (pH-H_2O < 5) of low organic matter (< 3.4%) in the humid regions of tropical America.

Plant regeneration

Grazing was also found to be detrimental for perennation of *Cm* by vegetative pathways. This is evident from the rapid decline in time of stolon length of *Cm* (< 2 m/m^2) and the number of rooted stolons (< $2.2/m^2$) at both SR's. Studies with *C. virginianum* (Jones and Clements, 1987), *Desmodium uncinatum* cv. Silverleaf and *D. intortum* cv. Greenleaf at Beerwah, Queensland, Australia (Jones, 1989) and with *M. atropurpureum* at Samford, Queensland, Australia (Jones and Bunch, 1988a), showed that increasing SR had negative effects on stolon and rooting development of these species, but at low SR these species persisted to some extent by crown enlargement, increased stolon numbers and nodal rooting. However, it should be indicated that SR (1.1 to 1.7 steers/ha) at which these species persisted were far below those used in our experiment.

On the other hand, the higher stolon length and rooted node numbers of *Ap* at the HSR demonstrates that this species is more grazing tolerant than *Cm*. The mean stolon length and number of roots/m^2 of *Ap* were higher in the *Bh* than in the *Bb* mixture and this was undoubtedly associated with the displacement of *Bh* by *Ap* in the second grazing year (Fig. 2.2.). However, in the last six grazing months the invasion of weeds affected persistence of *Ap* as seen from the abrupt decline in stolon length and the number of roots of *Ap* in the corresponding period.

Stolon length measured for *Ap* in this study was very high, reaching up to 184 m/m^2 in the mixture with *Bh* at the HSR. Experiments in Queensland, Australia with *Arachis* spp. (glabrata type) and white clover (*Trifolium repens*) (Jones, 1982; Curll and Wilkins, 1983) showed similar increases in stolon density with time under subtropical conditions (Vos and Jones, 1986). This demonstrates that *Arachis* spp. have a great potential for persisting by vegetative mechanisms under good soil moisture conditions as in this experiment. Experience with *Ap* at Samford, Queensland, Australia indicated lower stolon and rooting densities (Jones, 1993) compared to the findings in this study. At Samford there is a defined dry, cool period and lower rainfall than in Guápiles, which may explain lower regeneration of *Ap* in the experiment of Jones. Depending on SR and grass species there were some 311 to 1170 *Ap* roots/m^2 > 1 mm in diameter in October 1992. More than 60% of these roots were adventitious which is a good indication that *Ap* depended heavily on vegetative means of perennation in this environment. Under drier conditions with *Ap* at Samford, Queensland, Australia, Jones (1993) found that a high percentage of roots > 1 mm in diameter were taproots, suggesting that seed reserves played an important role in seedling recruitment where moisture is limiting nodal rooting. A grazing experiment with *Ap* in the Llanos of Colombia with a defined dry period also showed that seed reserves played an important role in seedling recruitment of this species (Grof, 1985).

CHAPTER 4

BOTANICAL COMPOSITION AND NUTRITIVE VALUE OF THE DIET SELECTED BY OESOPHAGEALLY-FISTULATED STEERS GRAZING GRASS-LEGUME MIXTURES IN THE ATLANTIC ZONE OF COSTA RICA.

4. BOTANICAL COMPOSITION AND NUTRITIVE VALUE OF THE DIET SELECTED BY OESOPHAGEALLY-FISTULATED STEERS GRAZING GRASS -LEGUME MIXTURES IN THE ATLANTIC ZONE OF COSTA RICA.

Introduction

The inclusion of legumes in sown grasslands offers a good option for improving animal production in the tropics. Experience in Costa Rica and elsewhere showed that liveweight gains/ha from legume based pastures were 35 to 70% higher than that of unfertilized pure improved grass pastures and 100 to 300% higher than that produced from unimproved native pastures (Toledo and Morales, 1979; 't Mannetje and Jones, 1990; Lascano, 1993; Hernandez et al., Chapter 6 of this thesis). Significant improvement in milk yields per hectare is also possible from legume grass mixtures compared to pure grass pastures (Stobbs and Thompson, 1975; Lascano and Avila, 1991) even though milk yields per ha from legume mixtures do not approximate those of heavily fertilized improved grass pastures (Stobbs, 1971; Archibald 1984). Under Australian conditions milk yields from Jersey cows of 6000 to 8000 kg/ha have been reported from grass legume mixtures (Stobbs, 1972; Byford and O'Grady, 1973).

The improvements in animal production from legume grass pastures is related to the high nutritive value of legumes, apart from their role in providing a N input in the pasture system, thereby improving the overall dry matter yield and the nutritive value of forage. Because legumes are capable of fixing substantial amounts of N, the crude protein (CP) concentration of legumes is usually higher than that of grasses at a similar stage of growth (Minson, 1985; Wilson and Minson, 1980). This is of considerable importance since the CP concentration of most tropical grasses frequently falls below the critical value of 7%, below which dry matter intake is becoming depressed (Siebert and Kennedy, 1972; Humphreys, 1991).

Apart from CP, dry matter digestibility and voluntary intake of legumes is generally higher than those of tropical grasses, except at the earliest stages of growth, where they may be similar (Whiteman, 1980; Hacker and Minson, 1981; Norton, 1982). The decrease in nutritive value of herbage with age is a phenomenon observed throughout the tropics (Rocha and Vera, 1981; Wilson, 1982; Abaunza et al., 1991). As the pasture matures the fibre content increases leading to a reduction in quality (Van Soest, 1982). However, legumes have a slower rate of decline in digestibility and crude protein concentration than grasses

(Wilson 1982; Abaunza et al., 1991). This has consequences for animal production and therefore the ability of animals to select at least part of their diet from legumes contributes greatly to the higher production from legume based pastures.

Selection by grazing animals of herbage species may also be affected by season. It has been shown with a number of grass-legume mixtures that animals preferentially graze the grass at the beginning and the legume at the end of the growing season when the quality of the companion grass declines (Stobbs, 1977; Gardener, 1980b; Lascano, 1983). In many situations, legumes retain green leaves longer into the dry season than grasses do and under those conditions, legumes offer additional benefits to the feed supply (Gardener, 1980b; Lascano et al., 1981; Mclean et al., 1981; Böhnert et al., 1986).

The results from cutting experiments at Los Diamantes in the Atlantic Zone of Costa Rica showed that there was high variation in quality of grasses and legumes both within and between species (CATIE, 1989, 1990; Roig, 1989; Vallejos et al., 1989). This offers some flexibility in selecting adapted species with high nutritive value for the region. The high yielding adapted species such as *Brachiaria brizantha, B. humidicola* and *Panicum maximum* have a higher digestibility of dry matter and crude protein concentration, as well as a higher leaf:stem ratio than most of the dominant grasses (*Axonopus compressus, Ischaemum ciliare,* etc.) found in the Atlantic Zone of Costa Rica (Vallejos, 1988; CATIE, 1990). Leafiness in pasture plants is commonly associated with forage quality because there is usually a positive correlation between leaf percentage in a given plant species and the protein and mineral composition and DM digestibility (Laredo and Minson, 1973).

However from a nutritional standpoint, it is important to evaluate forage species under grazing conditions in order to take also into account acceptability of the species by the animals and this applies particulary to legumes. Some legume species, which may be well adapted to a particular region and show high yields of adequate *in vitro* dry matter digestibility, are being eaten less readily or are even rejected by grazing animals because of the presence of anti-nutritional factors (Hegarty, 1982; Villaquiran and Lascano, 1986; Barry and Blaney, 1987).

Although it is desirable that legumes should form a considerable proportion of the diet of grazing animals in the tropics, the legumes should not be too palatable either, otherwise they will be selectively grazed out of the mixture. This frequently occurs with legumes such as *Centrosema spp., Pueraria phaseloides* and *Neonotonia wightii* that are palatable and have poor mechanisms for persistence (Davison and Brown, 1985; Hurtado, 1988; Jones and Clements, 1987). In those cases lenient grazing is necessary to maintain the legume in the mixture (Roberts, 1980). Besides, heavy grazing of the legume should be avoided during flowering and seed set to permit a build up of seed reserves which is essential for seedling recruitment with some species.

This chapter reports on the nutritive value of selected grasses and legumes grown in mixtures and the diet selection of animals grazing these mixtures at two stocking rates.

Materials and methods

The experiment in which the measurements for this chapter were made is described in Chapter 2 of this thesis. There were mixtures of the grasses *Brachiaria brizantha (Bb)* and *B. humidicola* (*Bh*) with each of the legumes *Arachis pintoi (Ap)*, *Centrosema macrocarpum (Cm)* and *Stylosanthes guianensis (Sg)*. The mixtures were rotationally grazed at two stocking rates: LSR: 1.75 AU/ha and HSR: 3.00 AU/ha.

Measurements

Forage quality. Hand-plucked samples of green material were collected from the grasses and legumes starting from May 1990 and thereafter every two grazing cycles until September 1992. The samples largely consisted of green leaf and some young stem material. The material was dried at 65 ^{0}C for 48 hours, ground through a 1 mm screen and analyzed for *in vitro* dry matter digestibility (IVDMD) (Tilley and Terry, 1963) and N concentration (%CP = %N X 6.25).

Diet selection. In April 1991 six steers were fistulated at the oesophagus to measure diet selection (Torrel, 1954). The fistulated animals had been adapted to the legume-grass pastures for a period of four months. The botanical composition and quality of the diet selected were determined on six occasions starting in May 1991 and there after every two months until July 1992. These measurements were taken routinely for *Ap* with both grasses (*Bb* and *Bh)* while with *Sg* and *Cm*, measurements on diet selection were only possible with *Bh* until October 1991 because the dry weight percentage of both species fell below 6% (Chapter 2.). In the *Bb* plots, *Sg* and *Cm* actually disappeared in the first six grazing months and there were no measurements with these mixtures.

The oesophageally fistulated (OF) steers were fasted for 6 to 8 hours before they were used for sampling between 6.30 and 9.30 in the morning on the second day of the grazing period. For *Ap* diet selection was also determined on days 1, 3 and 5 of the grazing period on four dates from October 1991. Two OF steers were used to graze each paddock for about 20 minutes and an average sample size of about 1 kg extrusa was collected from each animal. Samples from the two steers in each paddock were combined and lightly squeezed through muslin cloth. One half of the sample was frozen for later determination of botanical composition using the microscope point-hit technique developed by Harker et al.(1964).
The components identified were green leaves and stem of the sown and volunteer species and dead material. The other portion of the extrusa was dried at 65 ^{0}C for 48 hours, ground through a 1 mm screen and analyzed for nitrogen and IVDMD.

At all sampling dates the yield and botanical composition of forage on offer before grazing were estimated. In each plot 10 quadrats (0.5 X 0.5 m) situated along transects within the paddock were cut and the samples were separated to determine dry weight of leaf and stem of sown species, and of volunteer species and dead herbage.

Statistical analysis and calculations

In order to measure the effect of sampling period on forage quality, the response variables were analyzed using analysis of variance for a split-plot design where treatments were assigned to the main plots and sampling periods to sub-plots (Steel and Torrie, 1980). For diet selection *Ap* mixtures were analyzed separately from the others, because there were 6 sampling dates, whereas with *Bh+Cm* and *Bh+Sg* there were only 3 sampling dates. With *Ap* the effect of grazing day on the composition and quality of the diet selected was measured by considering grazing day as sub-sub plot.
Least significant difference (LSD) and Duncan's new multiple range test were used to detect differences between means. For the crude protein concentration of the diet selected from *Ap* mixtures, a linear regression analysis was performed to describe the relationship between CP and amount of legume in the diet.

Selection for a legume is partly influenced by the amount available in the pasture. This has been overcome by expressing the selection as the selection index (SI) which is calculated as the % herbage in the diet over the % herbage on offer (after Van Dyne and Heady, 1965). Indices below 1.0 indicate negative, and above 1.0 positive selection, for the component.

Results

Forage quality

Grasses. Table 4.1. presents the mean IVDMD and CP concentration of hand-plucked green *Bb* and *Bh* grown with the three legumes and grazed at the two SR's. The mean IVDMD of the hand-plucked grass material was 65% and there was no significant difference in IVDMD of *Bb* and *Bh* at the same SR. However, IVDMD of the grasses at the HSR was significantly ($P < 0.05$) higher by 1.6 to 2.2 units than at the LSR. The legume species had no significant effect on IVDMD of the grasses, even though it was consistently 0.4 to 0.9 units higher for grasses grown with *Ap*, depending on the SR and grass species.

Over the grazing period there was significant ($P < 0.01$) seasonal variation in mean IVDMD of the green material of the grasses, which was about 62 % during the drier months of January to March compared to about 65% during the rest of the year (Fig. 4.1.).

The mean CP concentration of the green material of the grasses was 11.8%. SR had a significant ($P < 0.05$) effect on the CP concentration of the grasses, that at the HSR being steadily 0.5 to 0.8 units higher than at the LSR (Table 4.1.). The mean CP concentration of *Bb* grown with *Ap* was significantly ($P < 0.05$) higher than that grown with *Cm* or *Sg*. At the LSR the CP value of *Bh* was not significantly different for the three legume species, but at the HSR the CP value of *Bh* with *Sg* was significantly ($P < 0.05$) lower than when grown with *Ap* or *Cm*.

The CP concentration of the grasses in mixture with *Cm* or *Sg* decreased with time, whereas the opposite was observed when they were grown with *Ap* (Fig. 4.2.).
CP concentration of the green material averaged over SR and grasses increased from a mean of 11.3% in May 1990 to 13.6% in September 1992. However the rate of increase in CP was more striking with *Bh* than with *Bb*. Over the grazing period mean CP of the grasses varied in the same way as IVDMD did, but it stayed high in all grazing months.

Legumes. The data presented in Table 4.2. on IVDMD and CP value of the legumes at the two SR's were averaged across grasses, because there was no significant effect of grass species on the quality of the legumes. The mean IVDMD and CP concentration of the green legume material were significantly ($P < 0.01$) different between legume species, with mean IVDMD of *Ap* across SR being 8.5 and 7.7 units higher than those of *Cm* and *Sg*, respectively. There was no significant effect of stocking rate on IVDMD of *Ap* and *Sg*, but

Table 4.1. The effect of two stocking rates (LSR = 1.75 and HSR = 3.00 AU/ha) on the mean *in vitro* dry matter digestibility (% IVDMD) and crude protein concentration (% CP) of hand-plucked samples of *Brachiaria brizantha* (*Bb*) and *B. humidicola* (*Bh*) associated with *Arachis pintoi* (*Ap*), *Centrosema macrocarpum* (*Cm*) and *Stylosanthes guianensis* (*Sg*).

	LSR		HSR		Mean of
	Bb	*Bh*	*Bb*	*Bh*	legume
Legume	% IVDMD				
Ap	64.4	64.6	66.1	66.6	65.4a*
Cm	63.9	63.7	65.6	65.9	64.8a
Sg	63.8	64.2	65.4	66.0	64.8a
Mean of SR ($LSD_{.05}$ = 1.4)	64.1		65.9		
	% CP				
Ap	11.7	11.8	12.8	12.9	12.3a
Cm	11.0	12.1	11.8	12.8	11.9b
Sg	10.7	11.9	11.6	11.1	11.3c
Mean of SR ($LSD_{.05}$ = 0.3)	11.5		12.2		

* values within the same column with different letters are significantly different ($P < 0.05$) according to Duncan multiple range test.

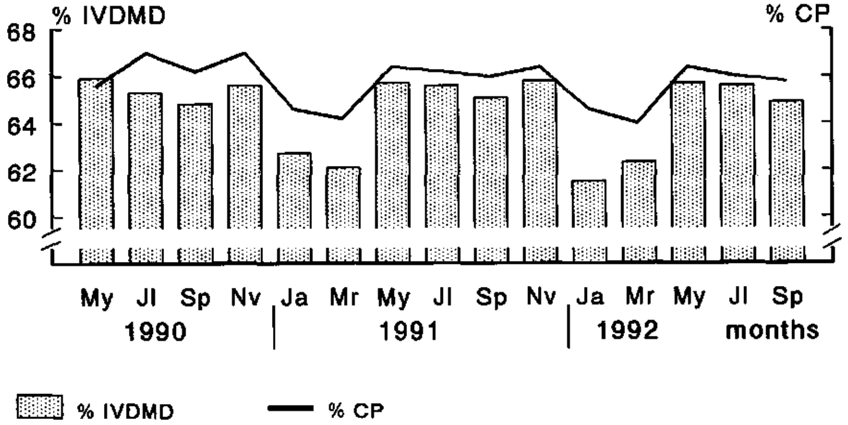

Figure 4.1. Variation in the mean percentage *in vitro* dry matter digestibility (% IVDMD) and crude protein concentration (% CP) of the hand-plucked green herbage material over the 2½ years of grazing.

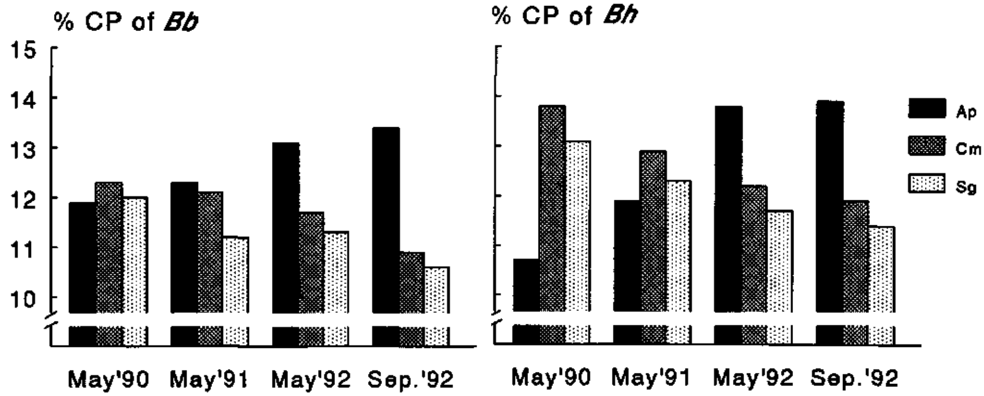

Fig. 4.2. Changes in time in the crude protein concentration (% CP) of hand-plucked green material of *B. brizantha (Bb)* and *B. humidicola (Bh)* from *A. pintoi* (*Ap*), *C. macrocarpum (Cm)* and *S. guianensis* (*Sg*) mixtures.

the IVDMD of *Cm* at the LSR was significantly (P < 0.05) lower than that at the HSR, although the difference was only 1.5 units.

The mean crude protein concentration of *Cm* and *Ap* did not differ significantly, but that of *Sg* was significantly (P < 0.05) lower than that of the other species. There was no SR effect on the CP concentration of the legumes.

Like the grass species there was also a marked seasonal variation in IVDMD and CP

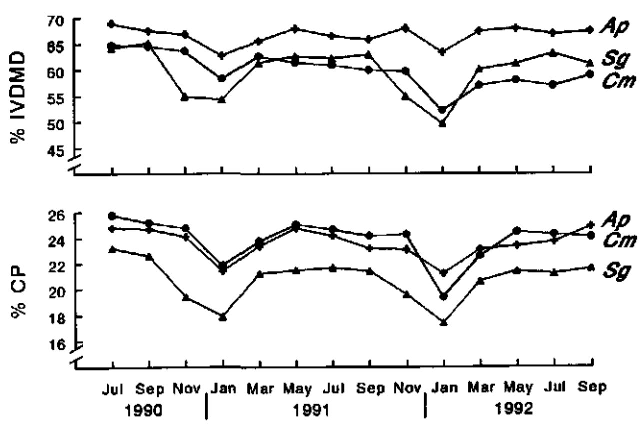

Fig. 4.3. Changes in mean *in vitro* dry matter digestibility (% IVDMD) and crude protein concentration (% CP) of hand-plucked samples of *S. guianensis (Sg)*, *C. macrocarpum (Cm)* and *A. pintoi (Ap)*.

Table 4.2. The effect of two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha) on the mean *in vitro* dry matter digestibility (% IVDMD) and crude protein concentration (% CP) of hand-plucked samples of *A. pintoi, C. macrocarpum* and *S. guianensis* over 2½ years of grazing.

	% IVDMD		Mean	% CP		Mean
Stocking rate	LSR	HSR		LSR	HSR	
A. pintoi	65.6	65.9	65.7a*	24.0	23.9	23.9a
C. macrocarpum	56.5	58.0	57.2b	23.7	23.5	23.6a
S. guianensis	57.8	58.3	58.0b	20.9	20.2	20.5b

* values within the same column with different letters are significantly different ($P < 0.05$) according to Duncan multiple range test.

Table 4.3. The mean dry matter yield (ton/ha) and botanical composition (DW %) before grazing of grass-legume mixtures (*Bh+Ap, Bb+Ap, Bh+Sg* and *Bh+Cm*) grazed at two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha).

		Botanical composition (DW %)						
Mixture	DM yield	Grass		Legume		Vol spp.		Dead
	ton/ha	L	S	L	S	L	S	
[1]*Bh+Ap*								
LSR	6.0	34.1	14.8	13.8	10.9	3.2	6.3	16.9
HSR	4.1	18.1	6.8	27.6	22.0	6.0	8.0	11.5
	**	**	**	**	**	*	*	*
[1]*Bb+Ap*								
LSR	6.8	35.8	31.5	6.0	3.7	0.5	1.5	21.0
HSR	4.9	35.4	25.0	11.0	8.0	3.0	4.6	13.0
	**	NS	*	**	**	**	*	*
[2]*Bh+Sg*								
LSR	6.2	38.5	18.9	6.0	11.1	3.3	6.2	16.0
HSR	3.9	49.0	19.1	2.9	5.3	4.3	6.4	13.0
	**	NS	NS	**	**	NS	NS	*
[2]*Bh+Cm*								
LSR	5.3	4.2	2.2	1.4	0.6	21.4	45.7	24.5
HSR	3.7	21.4	8.8	4.8	2.1	19.9	31.0	12.0
	**	**	**	*	*	NS	**	**

* LSD significant at $P < 0.05$, ** LSD significant at $P < 0.01$. L = Leaf, S = Stem
[1]Mean of 6 sampling dates, [2]Mean of 3 sampling dates.

Table 4.4. Mean botanical composition (DW %) of the diet selected from grass-legume mixtures (*Bh+Ap*, *Bb+Ap*, *Bh+Sg* and *Bh+Cm*) grazed at two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha).

	Diet composition (DW %)						
	Grass		Legume		Vol spp.		Dead
	L	S	L	S	L	S	
Bh+Ap							
LSR	65.7	2.2	27.8	1.7	1.6	0.0	1.0
HSR	35.4	5.1	49.8	3.2	3.4	0.0	3.1
	**	*	**	NS	NS	NS	*
Bb+Ap							
LSR	84.4	2.1	11.0	1.0	1.0	0.0	0.5
HSR	66.8	6.3	21.8	1.8	1.3	0.0	2.0
	**	*	**	NS	NS	NS	*
Bh+Sg							
LSR	85.0	1.0	8.5	3.0	1.7	0.0	0.8
HSR	81.9	7.1	3.6	1.2	2.0	1.5	2.7
	NS	*	**	NS	NS	*	*
Bh+Cm							
LSR	55.9	2.1	14.0	2.3	22.1	1.8	1.8
HSR	72.4	6.7	11.9	2.1	2.8	1.0	3.1
	**	*	NS	NS	**	NS	*

L = Green leaf S = Stem [1]Mean of 6 sampling dates [2]Mean of 3 sampling dates
* = LSD significant at P < 0.05 ** = LSD significant at P < 0.01. NS = Not significant

concentration of the green material of the legumes, which was significantly (P < 0.01) different between legume species (Fig. 4.3.). The IVDMD of the green material of *Sg* receded below 55% and CP concentration below 18% in November, which coincided with profuse flowering of this species (Chapter 3). Between November and March the IVDMD and CP concentration of all three legumes were depressed, but it is noteworthy that IVDMD of *Ap* remained above 65%.

Available dry matter yield, botanical composition on offer and diet selection

Dry matter yield and botanical composition on offer. It was not possible to compare data on grass-legume mixtures, except for those of *Ap*, because *Sg* and *Cm* were only sampled three times whilst mixtures of *Ap* had six samplings. The mean DM yield before grazing at the

LSR was significantly (P < 0.05) higher than at the HSR (Table 4.3). Mean DW percentage of *Ap* was higher with *Bh* than with *Bb* and higher at the HSR than at the LSR. The amount of *Sg* in the mixture at the LSR was twice that at the HSR, and at both SR's *Cm* did not represent more than 7% of total DM on offer. The contribution of volunteer species to DM yield was insignificant, except for the *Bh+Cm* mixtures in which it was greater than 45%. In all mixtures and SR's dead material represented more than 10% of total forage on offer.

Diet composition. It is evident that OF steers selected mostly leaf material of the sown species (Table 4.4.). Volunteer species and dead material were hardly eaten except in *Bh+Cm*. In *Ap* containing mixtures the diet of OF steers constituted a high proportion of grass leaf at the LSR, but at the HSR in *Bh+Ap* the diet contained more than 50% of *Ap*. Mean DW% of *Sg* in the diet was higher at the LSR than at the HSR while the opposite was observed for *Ap*. The composition of *Ap* in the diet varied significantly in time (P < 0.01) and this was highly correlated (r = 0.91) with variation in the amount of *Ap* on offer (Fig. 4.4.). *Ap* in the extrusa averaged over SR ranged from 13.5 (July 1991) to 23.1% (April 1991) for *Bb* while for the *Bh* it ranged from 23.5 (May 1991) to 67.5% (October 1991).

Effect of grazing period. There was some effect (P < 0.01) of day of grazing on diet composition in *Ap* mixtures at the two SR's which is illustrated in Fig. 4.5. The mean percentage of *Ap* in the extrusa was more or less stable during grazing. The proportion of grass plus legume leaf material in the diet decreased with progressive grazing, but even on the fifth day this accounted for more than 70% of the diet, except for *Bh* at the HSR which averaged 59%. At the HSR total leaf contribution of sown species to the diet on day 3 and 5 of grazing was 6.8 to 9 units lower than at the LSR for *Bb*, while that of *Bh* was 20.2 to 22.5% lower for the HSR. The proportion of dead material in the diet increased as the plots were grazed down, but this increase was more striking for the HSR. Volunteer species did not form a high portion of the diet, except in the Bh+Ap mixture at the HSR in which the amount of volunteer species in the diet significantly (P < 0.01) increased from 4.8% on day 1 to 18.1% on day 5 of grazing.

Selection index. Selection indices of the sown grass leaf material were high and they were not affected by SR except for *Bh+Cm*, which had a higher leaf selection at the LSR

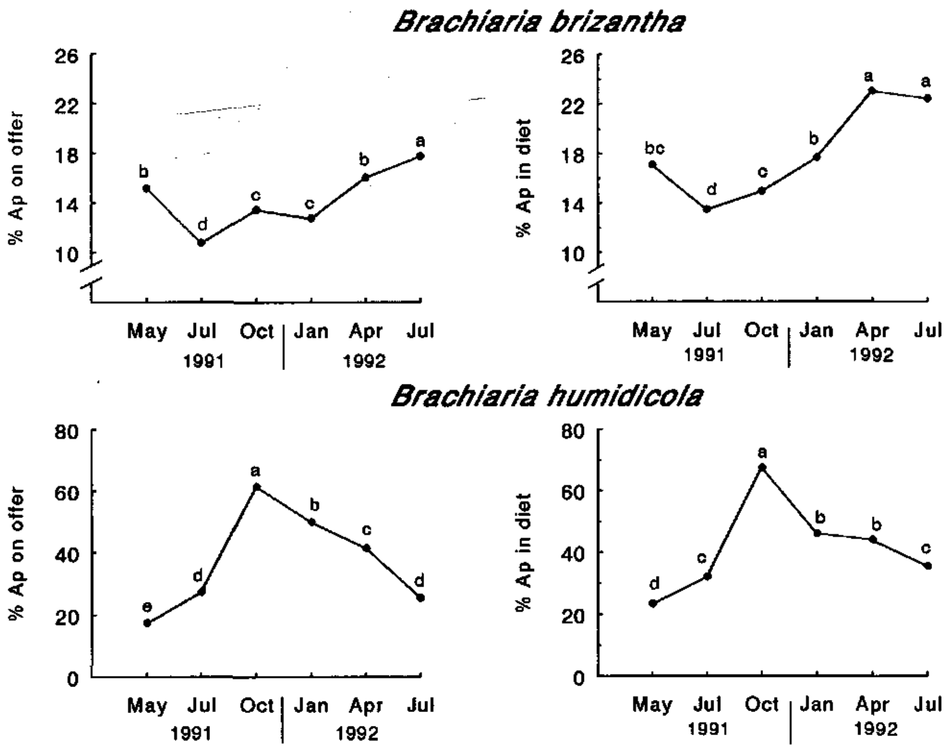

Fig. 4.4. Variation in time of the mean DW % of *A. pintoi* (*Ap*) on offer with *B. brizantha* *(Bb)* and *B. humidicola* *(Bh)* and in the DW % of *Ap* in the diet of OF steers grazing these mixtures (different letters (a-e) indicate significantly different values (P < 0.05) according to Duncan multiple range test.

(Table 4.5.). The selection index of *Sg* was lower than that of *Cm* and *Ap*. There were no marked differences in selection index of *Ap* between grasses and SR's, and in all mixtures it was above 1 indicating positive selection for *Ap* in the mixtures. The selection index for *Cm* was the highest of all legumes and at the LSR it was four times that at the HSR.

Selection index was calculated for total material of volunteer species because only a very small quantity of stem was selected from this component. In all treatments animals rejected volunteer species as seen from the low selection indices (Table 4.5.).

Table 4.5. Selection indices of leaf (L) stem (S) and total material (T) of the sown grasses and legumes and of total material of volunteer species (Vol.spp.) measured with four grass-legume mixtures (*Bh+Ap*, *Bb+Ap*, *Bh+Sg* and *Bh+Cm*) grazed at two stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha). Calculated from Tables 4.3. and 4.4.

Mixture	Grass			Legume			Vol. spp.
	L	S	T	L	S	T	
[1]*Bh+Ap*							
LSR	1.9	0.1	1.3	2.0	0.1	1.2	0.2
HSR	1.9	0.7	1.6	1.8	0.1	1.1	0.2
[1]*Bb+Ap*							
LSR	2.3	0.1	1.3	1.8	0.3	1.2	0.5
HSR	1.9	0.2	1.2	2.0	0.2	1.2	0.2
[2]*Bh+Sg*							
LSR	2.2	0.1	1.5	1.4	0.3	0.7	0.2
HSR	1.7	0.4	1.3	1.2	0.2	0.6	0.3
[2]*Bh+Cm*							
LSR	13.3	0.9	9.0	10.0	3.8	8.1	0.3
HSR	3.4	0.8	2.5	2.5	1.0	2.2	0.1

[1]Means of 6 sampling dates [2]Means of 3 sampling dates

Diet quality. Table 4.6. presents the mean IVDMD and CP percentage of the diet of OF steers grazing the 2 mixtures at the two SR's. IVDMD of the diet averaged over SR ranged from 62.4 to 65.8% and mean CP ranged from 11.4 to 16.5%. At the LSR IVDMD of the diet was invariably 2.1 to 4.5 units above that at the HSR which was significant ($P < 0.05$). The CP concentration of the diet with *Cm* and *Sg* mixtures at the HSR was significantly ($P < 0.01$) 1.5 to 2.4 units lower than that at the LSR, whereas with *Ap* mixtures the CP level of the extrusa was 2.1 to 2.5 units higher ($P < 0.01$) for the HSR than for the LSR. IVDMD of the extrusa from *Bb+Ap* was similar to that of *Bh+Ap*, but CP concentration of the extrusa was significantly ($P < 0.01$) different between the two mixtures.
CP of the extrusa averaged over SR was 16.5% for *Bh+Ap* which was 2.4 units above that of *Bb+Ap* mixture.

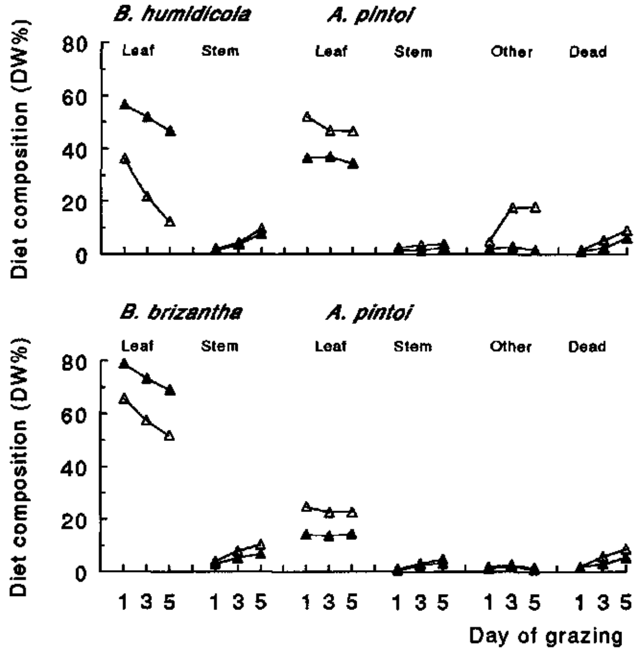

Fig. 4.5. The effect of stocking rate (LSR ▲—▲ (1.75 AU/ha) and HSR △—△ (3.00 AU/ha) on the mean botanical composition of the diet selected from *B. brizantha/A.pintoi* and *B. humidicola/A. pintoi* mixtures on day 1, 3 and 5 of grazing.

Table 4.6. The effect of stocking rates (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha) on the mean *in vitro* dry-matter digestibility (IVDMD) and crude protein (CP) concentration of the diet of OF steers grazing *A. pintoi (Ap)* with *B. brizantha (Bb)* and *A. pintoi, S. guianensis (Sg)* and *C. macrocarpum (Cm)* grown with *B. humidicola (Bh)*.

	% IVDMD			% CP		
Mixture	LSR	HSR	Mean	LSR	HSR	Mean
[1]*Bh+Sg*	65.9	63.1	64.5	12.6	10.2	11.4
[1]*Bh+Cm*	60.2	64.7	62.4	12.9	11.4	12.1
[2]*Bh+Ap*	66.6	64.5	65.5	15.3	17.8	16.5
[2]*Bb+Ap*	66.9	64.8	65.8	13.1	15.2	14.1

[1]Means of 3 sampling dates [2]Means of 6 sampling dates

The IVDMD and CP percentages of the diet of OF steers grazing *Cm* and *Sg* with *Bh* were more or less stable in time. With *Ap*, IVDMD of the diet did not show marked changes over time but CP concentration of the extrusa varied significantly ($P < 0.01$). The CP concentration of the diet averaged accross SR ranged from 14.6 (May 1991) to 17.2% (April 1992) for *Bh+Ap*, while that of *Bb+Ap* ranged from 13.3 (July 1991) to 15.7% (April 1992). The variation of CP in the extrusa with time can be attributed to the variation in the contribution of *Ap* to the diet (Fig. 4.6.). Pooling data over grass species and SR, the linear regression of CP% in the diet against the percentage of *Ap* in the diet accounted for 89% of the variance in the relationship (Fig. 4.6.).

Effect of grazing period on diet quality

The effect of day of grazing on mean % IVDMD and CP concentration of the extrusa from *Ap* mixtures at the two SR's is shown in Table 4.7. Mean IVDMD of the extrusa decreased significantly ($P < 0.05$) as the plots were grazed down, but IVDMD was always above

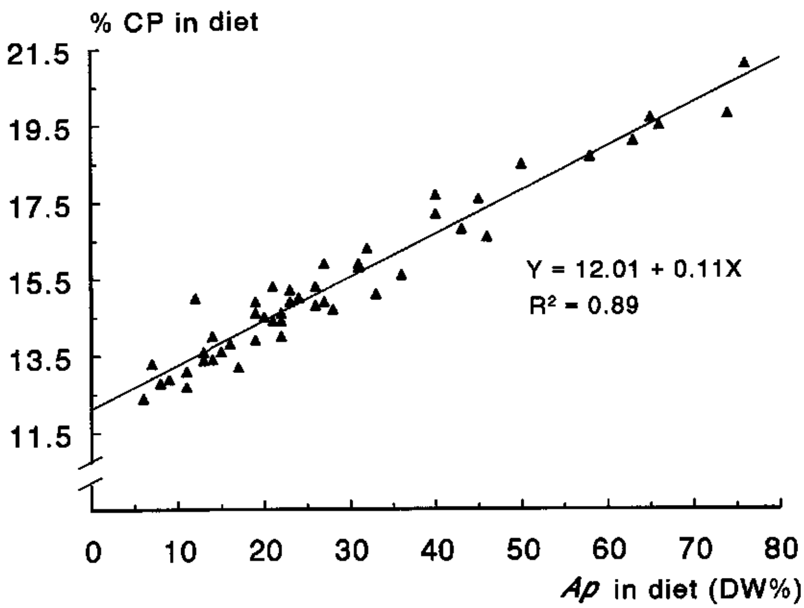

Fig. 4.6. The relationship between the percentage of crude protein (CP) in the diet selected from *Ap* mixtures and the DW % of *A. pintoi (Ap)* in the diet.

61.5%, except for *Bh+Ap* at the HSR in which it averaged only 54.7% on day 5 of grazing. The sharp decrease in IVDMD of the diet from *Bh+AP* at the HSR coincided with a marked increase in volunteer species that are of low quality. CP concentration of the diet on the first grazing day decreased by 0.9 to 2.3 units as the mixtures were grazed down, but it remained above 15% at the HSR with both mixtures (*Bb+Ap* and *Bh+Ap*).

Table 4.7. The effect of stocking rate (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha) on the mean *in vitro* dry-matter digestibility (% IVDMD) and crude protein concentration (% CP) of the diet from OF steers grazing *A. pintoi* with *B. humidicola (Bh)* and *B. brizantha (Bb)* on days 1, 3 and 5 of the grazing period (October 1991 to July 1992).

	LSR		HSR	
Grass	*Bh*	*Bb*	*Bh*	*Bb*
Days		% IVDMD		
1	65.9a*	66.8a	65.2a	64.6a
3	63.5b	63.1b	58.5b	62.1b
5	62.6b	62.4b	54.7c	62.0b
Mean	63.4	64.1	59.5	62.9
Days		% CP		
1	14.6a	13.4a	16.5a	15.8a
3	13.8b	12.2b	15.9b	15.1b
5	13.1b	11.1c	15.6b	14.8b
Mean	13.9	12.2	16.0	15.2

* values within the same column with different letters are significantly different ($P < 0.05$) according to Duncan multiple range test.

Discussion

Forage quality

Grasses. The mean IVDMD of the hand-plucked samples of the grasses in this study was 65% which was similar to or higher than values reported for leaf digestibility of these species and other improved tropical grasses such as *B. decumbens, B. ruziziensis* and *P. maximum* (Abuanza, 1982; Vallejos et al., 1989; Abaunza et al., 1991). Throughout the grazing period the grasses maintained high CP concentration (> 10.5%) although there was some seasonal variation. The high CP levels of the grasses may not be associated only with good soil fertility, but also to nitrogen being transferred from the associated legumes to the grasses. In less than three years the CP concentration of the grasses increased by 1.5 to 3.2 units when grown with *Ap* and similar increases were also detected in other grazing experiments (Whitney and Green, 1969; Bönhert et al., 1986; CIAT, 1986; Lascano and Thomas, 1988). Experience in Carimagua, Colombia, showed that the *Brachiaria* spp. maintained high CP in mixtures with *Ap* even in the dry season (> 7.0%) (Lascano and Thomas, 1988). This is of great significance for animal production when it is considered that the CP concentration of improved grasses grown alone frequently falls below 5% in the dry season leading to heavy weight losses of cattle. Grazing studies by Bönhert et al. (1986) in Carimagua, Colombia, also demonstrated that the CP concentration of *Andropogon gayanus* was higher when grown with *Pueraria phaseloides, Zornia latifolia* and *Stylosanthes capitata* than in pure stands.

However, although CP of the hand-plucked green grass material remained high, the decreasing trend in CP of the grasses grown with *Cm* and *Sg* is a good indication of soil N depletion. In these mixtures the CP concentration decreased by 1.5 to 3 units during the experimental period. This may be associated with a steep decline in the proportion of *Cm* and *Sg* in the first and second grazing years. Generally, following deforestation N status of improved grasses is very high, but as soil fertility is depleted so is quality of the pasture.

The quality of the grasses at the HSR was somewhat higher than at the LSR which is in agreement with results of other experiments (Eng et al., 1978; Hurtado, 1988; Ibrahim, 1990; 't Mannetje and Jones, 1990). The increase in quality of herbage with increasing SR is explained by the presence of young leafy shoots of high quality (Hacker and Minson, 1981; Ibrahim, 1990). Besides, when pastures are grazed at HSR there is a low carry over of aged lignified herbage material.

Legumes. The legume species differed in quality. Mean CP concentration of the legumes ranged between 17 to 26% which is in keeping with values of CP reported for leaf fractions of these and other tropical legumes elsewhere (McIvor, 1979; Lascano and Thomas, 1988; Abuanza et al., 1991). A higher CP concentration of *Ap* and *Cm* over that of *Sg*, probably reflects a difference in N fixation of the species. Some authors have noted that *Stylosanthes* fix less N compared to other tropical legumes but this is highly dependent on legume DM yield (Henzell et al., 1966).

Mean IVDMD of hand-plucked green material of *Ap* was 65.7% which was similar to that of the grasses, but higher than for *Cm* (57.2%) and *Sg* (58.0%). This supports results from other grazing experiments with *Ap* in Costa Rica (Hurtado, 1988; Gonzalez, 1992) and on the acid infertile soils of Carimagua, Colombia where there is a definite dry season (Lascano and Thomas, 1988). IVDMD of *Ap* was higher than that of the majority of tropical legumes and this means that it is not only important for furnishing protein but also to supply energy.

During the flowering period IVDMD of *Sg* receded by 10 to 14 units which has not been reported previously in studies quantifying seasonal variations in quality of *Stylosanthes* spp. (McIvor, 1979; Gardener et al., 1982; Roig, 1989). Grazing studies at Turrialba in Costa Rica, showed that IVDMD of *Pueraria phaseoloides* and *Desmodium ovalifolium* also significantly decreased when the species flowered. During flowering there is usually a cessation in green leaf production (Cameron and 't Mannetje, 1977; Gardener et al., 1982). A high percentage of stems and dry leaf material in hand-plucked samples was presumably responsible for the sharp decline in IVDMD of *Sg* in this experiment. Some authors noted that IVDMD of stem material of *Stylosanthes* spp. was within 10 to 15 units lower than that of green leaf material, depending on the stage of growth and season (Gardener et al., 1982; Villaquirán and Lascano, 1986).

Seasonal effect on forage quality.

The quality of both grasses and legumes was depressed in the months of reduced precipitation, but the decline in quality was less pronounced than that observed with improved herbage species in regions with a prolonged dry season. In this experiment the mean digestibility of the grasses and *Ap* remained above 60% in the drier months, while results from *A. gayanus/S. capitata* and *A. gayanus/P. phaseloides* mixtures grazed in the Llanos of Colombia showed that IVDMD of the associated grass fell as low as 47% in the dry season (Böhnert et al., 1985,1986). Lascano and Thomas (1988) found that leaf IVDMD of the grasses also decreased in the dry period but IVDMD of *Ap* was highest in the dry season (67.0%) which is contrary to the results of this experiment. However these authors attributed low IVDMD of *Ap* in the wet season to fungal attack of the legume, which was not found in this experiment. Furthermore, the Atlantic zone of Costa Rica does not experience as dry a time of year as the Llanos of Colombia.

The reason for the decline in quality of the herbage material in the months of lower precipitation is not clear. There is evidence that ageing is delayed by water stress (Ludlow and Ng, 1974) and that the decline in N concentration (Wilson and Ng, 1975) and dry matter digestibility (Wilson, 1981) of water stressed plants with ageing is slower than for well watered plants. During the dry period dry matter yields decreased significantly (Chapter 2) and this conceivably resulted in a higher percentage of aged and senescent material in the dry than in the wet season.

Diet selection

Diet composition. The legume species differed in acceptance with *Sg* being the least and *Cm* the most preferred. However the SI of *Sg* (0.6 to 0.7) is considered high enough to ensure adequate liveweight gains. In a grazing study in Uganda, Stobbs (1969) reported higher preference of *Sg* than observed in this experiment. In Uganda OF steers selected 27.8% of *Sg* in the diet which represented 29.1% of DM on offer in the association with *Hyparrhenia rufa*. In general *Stylosanthes* spp. are less acceptable than other tropical legumes such as *Cm, Centrosema acutifolium* and *Ap* (Gardener, 1980b; CIAT, 1990; Abaunza et al., 1991), but there are differences between *Stylosanthes* species in preference. Villaquirán and Lascano (1986) noted that intake of *Stylosanthes macrocephala* was higher than that of *S. guianensis* var. *pauciflora*, and a lower intake of the latter was related to high leaf viscosity which is also a problem of *S. viscosa*.

The preferential grazing of *Cm* found in this study is in agreement with results of other grazing experiments in Colombia (CIAT, 1989, 1990; Lascano et al., 1990). At the LSR the contribution of *Cm* in the diet of OF steers was 8.1 times than that on offer. In this treatment volunteer species accounted for 67.1% of the green material at the LSR, the dominant species being *P. fasciculatum* which is very unpalatable (Martinez et al., 1993b). This resulted in a heavy grazing pressure not only on the more palatable *Cm* but also on *Bh* which represented 58% of the diet although it was only 6.6 % on offer. Heavy grazing of the legume was also reported in a grazing experiment with *Centrosema acutifolium* introduced into native pastures (CIAT, 1988). The results from that experiment demonstrated that OF steers grazing at 1.5 animals/ha had 77.4% *C. acutifolium* in the diet during the rainy season, whilst this species accounted for less than 19.0% of total available forage.

The selection index of *Ap* was always greater than 1 although there were significant differences in the proportion of *Ap* on offer with the two grasses and at the two SR's. This indicates that there was active selection for the legume at all levels of availability. Selection index measured for *Ap* in this study coincides with those measured in Costa Rica also in mixture with *Bb* at Guápiles (Hernandez et al., Chapter 6 of this thesis) and in mixture with *Cynodon nlemfuensis* at Turrialba (Gonzalez, 1992). The results from the grazing experiment in Turrialba showed that OF steers consistently selected more *Ap* in the diet than that on offer, whereas OF steers avoided *D. ovalifolium* in the mixture. Low palatability of *D. ovalifolium* has been associated by many workers to a high tannin concentration of this legume which is known to have deleterious effects on IVDMD (Hutton and Coote, 1966; Lascano and Salinas, 1982).

High selection of *Ap* was also measured in *Brachiaria* pastures at Carimagua, Colombia, where there is a defined dry season (Lascano and Thomas, 1988; Carulla et al., 1991). The result of this and the grazing experiment in Colombia manifested that *Ap* was positively selected during the entire grazing year. This is contrary to findings by Böhnert et al. (1985, 1986) on grass legume mixtures which showed that the legumes *P. phaseoloides, S. capitata* and *Z. latifolia* only constituted a significant portion of the diet at the end of the rainy and in the dry season.

The results of this and other grazing experiments elsewhere showed that OF steers selected mainly leaf material. A high percentage of green leaf material in the diet is considered important for animal production, since there is a high correlation between the amount of leaf in the diet and total intake of digestible nutrients (Laredo and Minson, 1973; Wilson and Minson, 1980; Hendricksen et al., 1981). Nutritional studies with dairy cows demonstrated that daily milk yields/cow were increased as dietary leaf levels were increased (Stobbs, 1978; Davison et al., 1985).

With *Ap* mixtures leaf of sown species in the diet remained high even on the 5th. day of grazing (> 55%). Similar results have been reported by Chacon and Stobbs (1976) with fertilized pure *Setaria sphacelata* cv. Kazungula pastures at Samford, Queensland, Australia. However results reported on dietary leaf levels by Davison et al., (1985) with fertilized *Panicum maximum* cv. Gatton at Kairi, Queensland, Australia, were significantly lower than in this study. Leaf/stem ratio of both grasses was high (> 1) which may explain the high dietary leaf levels of this study. The stem and dead material content of the diet was higher at the HSR than at the LSR, which is in agreement with data presented by other workers (Davison et al., 1985; Hernandez et al., Chapter 6 of this thesis). This may be associated with a limited choice of selection under heavy grazing, especially when grazing of the plots progresses ('t Mannetje and Ebersohn, 1980). Apart from this, a higher leaf content in the diet at LSR may be associated with higher DM yields which were 37 to 60 % higher for the LSR than the HSR, depending on the association.

Over the five days of grazing there were only small variations in the percentage of *Ap* in the diet. This is in accordance with results of other experiments with *Ap* in Costa Rica (Martinez et al., 1993b; Hernandez et al., Chapter 6 of this thesis) and with other grass legume mixtures (*Panicum maximum* cv. Gatton - *Neonotonia wightii* cv. Tinnaroo - *D. intortum* cv. Greenleaf) grazed at Kairi research station in Australia (Cowan et al., 1986).

Quality of diet. In general the OF steers selected a diet of relatively high IVDMD (60.2 to 66.9%) on day 2 of grazing, which may be associated with the high dietary leaf levels mentioned above. The low IVDMD of the diet from *Bh+Cm* (60.2%) was undoubtedly related to the presence of a high percentage of the volunteer *P. fasciculatum* which is of low IVDMD (Rivera-Brenes et al., 1959; Martinez et al., 1993b).

Mean CP concentration of the diet on the second grazing day (10.2 to 17.8%) was considered adequate for relatively high animal production. In mixtures with *Ap* at the HSR, CP of the diet was greater than 15% which is considered sufficient for milk yields above 12 kg/day providing energy and other nutrients are not limiting (N.R.C., 1978).

The high CP concentration from *Ap* mixtures can be attributed to the high DW percentage of *Ap* in the diet which was sometimes above 60% in *Bh* mixtures at the HSR. Dietary CP levels of *Ap* mixtures compare favourably with data from other studies. At Los Diamantes the grazing experiment of Hernandez et al., (Chapter 6 of this thesis) showed that OF steers grazing *Ap* in mixture with *Bb* consumed a diet of CP between 15 to 18% and similar values were reported when OF steers grazed *Ap* in mixtures with various *Brachiaria* spp. at Carimagua, Colombia (Lascano and Thomas, 1988).

CHAPTER 5

SOIL ORGANIC MATTER, NITROGEN AND BULK DENSITY UNDER GRASS-LEGUME PASTURES IN THE ATLANTIC ZONE OF COSTA RICA.

5. SOIL ORGANIC MATTER, NITROGEN AND BULK DENSITY UNDER GRASS-LEGUME PASTURES IN THE ATLANTIC ZONE OF COSTA RICA.

Introduction

After deforestation improved high yielding grasses such as *Panicum maximum, Hypharrhenia rufa, Brachiaria decumbens* and *B. ruziziensis* are usually cultivated without N fertilization or the inclusion of legumes. Initially pasture yields can be high (> 20 tons DM/ha) and are capable of supporting 2-3 animals/ha (Toledo and Morales, 1979; Toledo and Formoso, 1993). However, with time pasture productivity is not sustained mainly because of leaching of nutrients, weed invasion, soil compaction, and changing the forest nutrient recycling system to a much inferior and fragile one.

Although the primary reason for including legumes in pastures is to increase dry matter yields and the protein concentration of the grazing animals' diet, there is also the effect of maintaining or increasing soil fertility, especially its organic nitrogen content (Henzell, 1968; Vallis, 1985; Sánchez and Ara, 1991). This was already demonstrated in Queensland, Australia by Bruce (1965) who showed that *Centrosema pubescens* in regularly grazed pastures maintained soil nitrogen at its initial level in a newly cleared forest soil whilst a loss of 100 kg N/ha/year was recorded without a legume.

The amount of N recycled in legume-based pastures is dependent on the amount of legume in the pasture which in turn depends on the stocking rate, among other factors. A temporary increase in grazing pressure can increase legume growth but continued severe grazing often suppresses it depending on the species, so that N input by the legume may increase with a change in grazing management. Besides, since the rates of decomposition of plant material, faeces and urine in soil can vary (Simpson et al., 1974), stocking rate is likely to affect the balance between organic nitrogen accumulation and decomposition.

Nitrogen fixed by legumes is available for growth of the companion grass resulting in increased pasture productivity. This contributes to an increase of the soil carbon sink, thereby reducing net CO_2 emission after deforestation. Early studies of Henzell et al. (1966) and Barrow (1969) showed that there was a high accumulation of soil organic matter with grass legume mixtures. Increasing the organic carbon sink is of much importance considering that the largest contribution of CO_2 emission in Latin America resulted from increases in the area of degraded lands after deforestation, which mainly consisted of degraded pastures (Houghton et al., 1991). The loss of soil organic carbon after deforestation is less in pastures than in croplands (Detwiler, 1986) and pastures play a key role in the release of CO_2 to the atmosphere, due to the vast area they cover.

Apart from improving soil fertility, some workers noted that legumes can also play an important role in reducing soil compaction caused by treading (Alegre and Lara, 1991; Toledo, 1991). Stocking rate has been found to have the main effect on soil compaction, but the degree of compaction is also dependent on other factors such as growth habit of pasture species, soil texture and soil moisture (Curll and Wilkins, 1983; Reátegui et al., 1990; Escobar and Toriatti Dematté, 1991).

This chapter reports on soil nitrogen, organic carbon and bulk densities measured with four grass-legume mixtures grazed at two stocking rates.

Materials and Methods

In Chapter 2 a description of the climate, vegetation and soil of the experimental site was presented. The treatments consisted of a factorial (2 × 3 × 2) of two grasses (*Brachiaria humidicola* (*Bh*) and *B. brizantha* (*Bb*)), three legumes (*Arachis pintoi* (*Ap*), *Centrosema macrocarpum* (*Cm*) and *Stylosantes guianensis* (*Sg*)) and two stocking rates (1.75 AU/ha (LSR) and 3.00 AU/ha (HSR)) in a completely randomised design with two replicates.

In October 1992, soil samples were taken from *Cm* and *Ap* plots for analysis of N concentration (%N) and organic matter content (SOM). Samples were collected from each replicate by stratified random sampling taking 50 cores (5 cm diameter) to a depth of 10 cm. At the laboratory, recognisable living plant fragments were removed by hand. The samples were air dried, ground to pass a 2 mm screen, then sub sampled and ground to 0.5 mm. Organic carbon was determined by Walkely and Black's (1934) rapid titration method and nitrogen concentration (%N) was determined by Kjeldahl procedure. Bulk density measurements were taken at three depths (0-5, 5-10 and 10-15 cm). In each replicate 6 samples were randomly taken using 100 cm^3 (5 cm diameter) stainless steel cylinders. The samples were oven dried for 24 h at 105 °C.

Carbon (Cs, g C/g soil) and nitrogen (Ns, g N/g soil) contents of soil samples were converted to Total Organic Carbon, TOC (Mg/ha) and Total Nitrogen, TSN (Mg/ha), based on soil layer thickness, L (m), and bulk density, ρ_b (Mg/m^3):

$$TOC = Cs \times L \times \rho_b \times 10^2 \quad (1)$$

$$TSN = Ns \times L \times \rho_b \times 10^2 \quad (2)$$

Results

Soil fertility

Soil Organic Matter and Total Organic Carbon. The results on Soil Organic Matter (SOM) and estimated Total Organic Carbon (TOC) at the end of the 2½ year grazing period are shown in Table 5.1. In general SOM and TOC were very high with values ranging from 8.46 to 9.73% for SOM and from 45.5 to 49.8 t/ha for TOC. SOM and TOC at the LSR were significantly ($P < 0.01$) higher than at the HSR, although the differences were relatively small. There were no significant effects of legume and grass species on SOM and TOC, but these were slightly higher for *Ap* than for *Cm* mixtures, and for *Bb* than for *Bh*.

Table 5.1. Soil organic matter (% SOM) and estimated total organic carbon (TOC) measured from grass legume mixtures (*Bb+Ap, Bb+Cm, Bh+Ap* and *Bh+Cm)* grazed at two stocking rates (1.75 (LSR) and 3.00 (HSR) AU/ha) at the end of a 2½ year grazing period.

	% SOM			TOC (ton/ha)		
	LSR	HSR	Mean	LSR	HSR	Mean
Bb+Ap	9.73	8.79	9.26a*	49.6	46.3	47.9a
Bh+Ap	9.47	8.76	9.11a	49.8	45.6	47.7a
Mean of *Ap*	9.60	8.77		49.7	45.9	
Bb+Cm	9.63	8.64	9.13a	48.5	45.5	47.0a
Bh+Cm	9.45	8.46	8.95a	47.5	45.7	46.6a
Mean of *Cm*	9.54	8.55		48.0	45.6	
Mean of SR	9.57	8.67		48.8	45.7	
LSD (P = 0.05)	0.80			2.5		

* values in the same column with different letters are significantly ($P < 0.05$) different according to Duncan multiple range test.

Nitrogen. Mean of soil N concentration (%N) and estimated total nitrogen (TSN) are presented in Table 5.2. These were very high with N varying from 0.422 to 0.500%, while TSN ranged from 3.55 to 3.95 tons/ha. There were significant main effects of legume ($P < 0.001$) and grass species ($P < 0.03$) on N and TSN, but there were no interactions between treatments. N concentration and TSN were higher for *Ap* than for *Cm* mixtures, and for *Bh* than for *Bb* mixtures.

Table 5.2. Soil nitrogen concentration (% N) and estimated total soil nitrogen (TSN) measured from *A. pintoi (Ap)* and *C. macrocarpum (Cm)* in mixtures with *B. brizantha (Bb)* and *B. humidicola (Bh)* at two stocking rates (1.75 (LSR) and 3.00 (HSR) AU/ha) measured at the end of a 2½ year grazing period.

	% N		Mean	TSN (ton/ha)		Mean
	Bb	*Bh*		*Bb*	*Bh*	
+ *Ap*						
LSR	0.464	0.500	0.482	3.74	3.95	3.84
HSR	0.472	0.473	0.472	3.87	3.84	3.85
Mean of *Ap*	0.468	0.486	0.477a[1]	3.80	3.89	3.84a
+ *Cm*						
LSR	0.432	0.443	0.437	3.55	3.55	3.55
HSR	0.422	0.435	0.428	3.55	3.65	3.60
Mean of *Cm*	0.427	0.439	0.433b	3.55	3.60	3.57b
Mean of grass	0.447	0.462		3.67	3.74	
LSD (P = 0.05)	0.014			0.06		

[1] values within the same column and with different letters are significatly different ($P < 0.05$) according to LSD test.

Bulk density.

Means of treatments for soil bulk density (ρ_b) are given in Table 5.3. Analysis of variance showed significant main effects ($P < 0.01$) of SR and legume species on ρ_b for all three sampling depths. As expected ρ_b was greater at the HSR than that at the LSR but it was never above 1.0 g/cm^3. ρ_b was lower for *Ap* than for *Cm* mixtures at all sampling depths. There was some interaction between grass and legume species on ρ_b which was significant

(P < 0.05). With *Ap* there were only small differences in ρ_b between *Bb* and *Bh* at a given SR, while with *Cm*, it was significantly higher for *Bb* at all three depths sampled.

Table 5.3. The effect of stocking rate (LSR = 1.75 AU/ha, HSR = 3.00 AU/ha) on bulk density measured at three depths with grass legume associations (*Bb+Cm, Bb+Ap, Bh+Cm* and *Bh+AP)* measured at the end of a 2½ year grazing period.

	Bulk density (g/cm^3)			Mean of mixture		
Depth (cm)	0-5	5-10	10-15	0-5	5-10	10-15
Mixture						
Bb+Ap						
LSR	0.73	0.82	0.81			
HSR	0.82	0.85	0.83	0.77c	0.83c	0.82c
Bh+Ap						
LSR	0.75	0.84	0.81			
HSR	0.78	0.87	0.83	0.76c	0.85c	0.82c
Bb+Cm						
LSR	0.78	0.88	0.86			
HSR	0.92	1.00	0.95	0.85a	0.94a	0.90a
Bh+Cm						
LSR	0.79	0.87	0.86			
HSR	0.84	0.91	0.88	0.81b	0.89b	0.87b
Mean of SR						
LSR	0.76	0.85	0.83			
HSR	0.85	0.91	0.87			
*LSD (P = 0.05)	0.03	0.04	0.02			

Values within the same column with different letters are significantly different (P < 0.05) according to Duncan multiple range test.

Discussion

Soil fertility

The experiment was conducted on a fertile, well drained Eutric Hapludand which explains the relatively high values for SOM and TOC content. Estimated TOC of this experiment averaged 47.3 tons/ha (to 10 cm depth) over the grass-legume mixtures and SR's which corresponds favourably to that measured under primary forest by Veldkamp (1993) in the

Atlantic Zone of Costa Rica and by Escobar and Toriatti Dematté (1991) in the humid zone of Caquetá, Colombia.

Generally, after deforestation there are large reductions in the amount of soil carbon in time which is more pronounced for cropping (Cerri, 1986) than for pasture systems (Veldkamp, 1993). The results of Escobar and Toriatti Dematté (1991) demonstrated that the amount of carbon lost from *Paspalum notatum* pastures after 15 years of use, amounted to 25% of that found under the forest.

The high loss of organic carbon from native or natural pastures may be associated with the low productivity of the grasses dominating these pastures. In this experiment *Bb* yielded up to 30 tons DM/ha/year (Table 2.2.), and if these high yields are sustained in time, the total amount of organic carbon in the pasture system may be similar or even higher than that under primary forest. This is supported by results from grazing studies with *Desmodium uncinatum* pasture at Beerwah, Australia (Henzell et al., 1966) and with *B. decumbens/D. ovalifolium* mixture grazed in the humid tropics of Yurimaguas, Perú (Ayarza et al., 1987), both of which showed that there had been a considerable build up of organic matter with time with these mixtures.

Averaged accross mixtures SOM and TOC were 0.9 % and 3.1 t/ha higher at the LSR than at the HSR, respectively. This may be associated with higher standing DM yields at the LSR which were 30 to 65% above those at the HSR, depending on the grass and legume species (Table 2.2.). The results of Walker (1980) from grass legume mixtures and from Simpson et al. (1974) with fertlised pasture also indicated higher soil carbon with low than with high stocking rates.

N concentration and TSN averaged over treatments were respectively 0.04% and 0.27 t/ha higher with *Ap* than those with *Cm*. Over the grazing period N yields of *Ap* mixtures were considerably higher than those of *Cm* mixtures depending on grass and SR (Fig. 2.2.) which undoubtedly accounted for higher amounts of soil N with *Ap* mixtures. This is supported by results from other legume based pastures which showed that there was a positive relationship between DM yields of the legumes and the amount of N fixed added to the system (Erdman and Means, 1962; Henzell, 1968; Jones, 1972).

In general, yields of *Cm* and *Ap* were higher with *Bh* than with *Bb* (Table 2.3.) which is probably reflected in the higher soil N for *Bh*. In association with *Bb* the contribution of *Cm* to total N yield was insignificant (Fig. 2.3.) so that any differences in soil N concentration and TSN between *Ap* and *Cm* in this mixture should be credited to N fixation by *Ap*. At the HSR mean TSN of *Bb+Ap* was 320 kg/ha higher than that of *Bb+Cm* and this represents an annual rate of increase in TSN of about 128 kg/ha. This is within the range of values reported from grass-legume mixtures grazed under diverse ecosystems, even though it is higher than for most tropical legumes (Jones, 1967; Johansen and Kerridge, 1979; Vallis and Gardener, 1984; Vallis, 1985). The conditions under which this study was conducted favoured high DM yield of *Ap* year round, which contributes to the relatively high amounts of N fixed by *Ap* in this study. It should be mentioned that in this study *Ap* yielded more than 5 tons DM/ha in mixtures with *Bb* and *Bh* at the HSR (Table 2.2.) and this is higher than those reported for many tropical legumes grown in mixtures (Reynolds, 1982). SR had no significant effect on soil N concentration.

Bulk density

After 2½ years of grazing the results on bulk density showed that there had not been a great degree of compaction. Bulk density in the top 10 cm averaged 0.84 g/cm^3 which was not much higher than that reported under forest (0.78 g/cm^3), but considerably lower to the values reported for pastures grazed at similiar stocking rates over a similar time period (Walker, 1980; Pinzón and Amézquita, 1991). The soil of the experimental site is well structured with a low clay content which may partially explain the low bulk densities measured. Grazing studies with various grasses cultivated on different soil types in the Colombian Amazon showed that compaction was greater on soils of higher clay content with bulk density up to 1.5 g/cm^3 in the first 5-15 cm depth (Pinzón and Amézquita, 1991). Reátegui et al. (1990) found that grass legume-mixtures grown on heavy clay soils in the humid tropics failed to persist under grazing because of increased soil compaction with time. These workers noted that infiltration rates were as low as 0.125 cm/hour with some mixtures.

As anticipated bulk density was greater for the HSR than for the LSR which can be attributed to a higher intensity of treading. Increased treading causes greater packing of the soil particles and loss of larger pores in the soil mass leading to increased bulk density (Humphreys, 1991). In a four year grazing study with a grass-legume mixture (*S. sphacelata /M. atropurpureum/S. guianensis)* Walker (1980) found that bulk density (0-10 cm) increased lineary from 1.3 to 1.5 g/cm^3 as the stocking rate was increased from 1.2 to 3.3 steers/ha.

Bulk density measured for *Ap* was lower than that of *Cm* mixtures and this is presumably related to a high density of rhizomes and roots of *Ap*. Samples taken for measurements of roots and seed reserves of *Ap* showed that there was a high concentration of roots of this legume even up to 15 cm depth. Seeds of *Ap* are large (Rocha et al., 1985; Argel, 1993) and the high seed reserves of *Ap* (Chapter 3 of this thesis) may also contribute to lower bulk density observed in *Ap* mixtures. The additional benifit of reduced soil compaction with the inclusion of legumes was also reported in studies with *Centrosema pubescens* grown in monoculture and various grass legume mixtures in Perú (Alegre and Lara, 1991). These authors found that bulk density measured at the end of a five year grazing period was much lower with the legume monoculture and legume-grass mixtures than with natural pastures.

Cm actually disappeared from the mixtures with both grasses and the mean bulk density measured for *Bb+Cm* was much higher than for *Bh+Cm*. *Bb* has a clumped growth habit and in these pasture types compaction is usually greater than with creeping and stoloniferous grasses (Alegre and Lara, 1991; Toledo, 1991) because of repeated treading in defined paths between the tussocks or clumps. Results of Alegre and Lara (1991) showed that bulk density was higher and infiltration rates lower in mixtures which included the erect *Andropogon gayanus* compared to those which included *Bh* and *B. decumbens*. These workers measured higher infiltration rates in the crown area of the soil under *A. gayanus* (> 16 cm/hour) than between the grass plants (3.2 cm/hour), where animals walk.

CHAPTER 6

LIVEWEIGHT GAINS OF CATTLE GRAZING *Brachiaria brizantha* WITH OR WITHOUT *Arachis pintoi* AT TWO STOCKING RATES IN THE ATLANTIC ZONE OF COSTA RICA

6. LIVEWEIGHT GAINS OF CATTLE GRAZING *Brachiaria brizantha* WITH OR WITHOUT *Arachis pintoi* AT TWO STOCKING RATES IN THE ATLANTIC ZONE OF COSTA RICA [1]

Introduction

Cattle production from pastures is the main land use in the Atlantic Zone of Costa Rica. About 60% of the total deforested area is taken up by grasslands. The main agricultural products from this region are bananas, beef, milk, plantain, root and tuber crops and ornamental plants. Economically beef and milk production are second only to bananas, but the banana industry is for 80% foreign owned and the cattle industry is wholly Costa Rican owned and operated. Animal production is, however, being practised on a very extensive scale, with low levels of inputs and management. About 77% of the total area under pasture is dominated by very unproductive naturalised and native grasses, the main species being *Ischaemum ciliare*, *Axonopus compressus, Brachiaria radicans* and *Paspalum* spp. The remainder consists of sown grasses, of which the main ones are *Cynodon nlemfuensis* (14%), *Brachiaria* spp. (6%) and *Hyparrhenia rufa* (3%) (SEPSA-CNP, 1990). The use of pasture legumes is virtually unknown.

Relative to crop production, animal production on the grasslands which dominate this area is inefficient in terms of land use and there is an urgent need to increase production. More intensive animal production through pasture improvement would require less land for pastures and allow large areas in the Atlantic Zone to be replanted to forest.

Studies by the Tropical Agricultural Research and Education Centre (CATIE), the Ministry of Agriculture and Animal Production (MAG), the International Center for Tropical Agriculture (CIAT, Colombia) and Ibrahim et al. (1993) have shown that the humid, warm climate and the generally fertile volcanic soils are very well suited for pasture production, provided productive species, including pasture legumes are used. The unimproved native pastures produce 8 - 10 tons of DM/ha/annum of poor quality, which is about 30 - 35% of the potential production from well managed *Brachiaria* pastures (CATIE, 1989; Veldkamp, 1993). In addition, the nutritive value of forage from native pastures is of low digestibility (40 - 55%) and low crude protein concentration (frequently < 7%), compared to selected

[1] Authors: M. Hernandez, M.A. Ibrahim and L.'t Mannetje. Submitted to Tropical Grassland.

improved grasses with digestibility values ranging up to 64% and crude protein values of around 12% (Vallejos, 1988; CATIE, 1990; Ibrahim and 't Mannetje, 1994c).

However, many of the sown grass pastures are in an advanced stage of degradation because of overgrazing and the lack of nitrogen input, as no legumes are used and nitrogen fertilizer is applied only on a very limited scale in the Atlantic Zone for more intensive dairy production. The main weeds invading such degraded pastures are *Mimosa pudica*, *Ischaemum ciliare, Brachiaria radicans* and *Paspalum fasciculatum* (Ibrahim and 't Mannetje, 1994a).

Recent studies by CIAT in the Atlantic Zone have shown that a range of grasses and legumes is adapted to the climate and soils of the region (Vallejos, 1988; Roig, 1989). The most promising grass-legume mixture for the well drained soils of the region is *B. brizantha* cv Marandu (CIAT 6780) and *A. pintoi* (CIAT 17434, cv Amarillo in Australia, Cook et al., 1990) (Ibrahim and 't Mannetje, 1994b).

This paper reports on pasture dry matter yields, botanical composition, forage quality and selection and liveweight gains (LWG) of cattle grazing *B. brizantha* in monoculture without nitrogen or in combination with *A. pintoi* at two stocking rates.

Materials and methods

Site

The experiment was established in June 1989 at the MAG Experiment Station "Los Diamantes" at Guápiles (10° 13' N, 83° 47' W, 250 m.a.s.l.), with a mean annual rainfall of 4535 mm, with driest months receiving between 200 and 300 mm, a mean annual temperature of 25 °C (min. 19.5 °C, max. 30.5 °C) and a mean relative air humidity of 87%. The soil is of volcanic origin of medium to high fertility with a pH-H_2O of 5.6.

Pasture and animal management

The treatments consisted of a factorial of two pastures: 1) *B. brizantha* (cv Marandu, CIAT 6780) (*Bb*) and 2) *Bb* in association with *A. pintoi* (CIAT 17434) (*Bb+Ap*) and two stocking rates (SR) in a completely randomised design with two replicates. The SR's expressed as animal units of 400 kg liveweight (AU) selected were 1.5 (LSR) and 3.0 AU/ha (HSR). The actual SR's at the start of the grazing periods ranged between 1.4 and 1.7 AU/ha for the low and 2.5 and 3.2 AU/ha for the HSR, respectively. However due to the liveweight gains of the animals, the LSR at the end of the grazing periods ranged from 2.0 to 2.4 and from 3.6 -

4.2 AU/ha for the LSR and HSR, respectively. Actual nominal SR's were 3.0 and 6.0 an/ha. No fertilizer application was made in the 2.8 years of grazing.

For the LSR the paddock size in each replicate was 0.67 ha and for the HSR 0.33. Each of these paddocks was subdivided equally into 4 plots to establish a rotational grazing cycle of 21 days resting and 7 days grazing. The pasture treatments in each replicate were grazed by two zebu type animals averaging about 200 kg LW/head. The 16 animals (8 males and 8 females) were selected from a uniform group of animals four weeks after weaning. The animals were routinely treated for internal parasites and had free access to minerals and water. There were three contiguous periods of grazing with different groups of animals, starting on 22 June 1990, 27 January 1991 and 29 January 1992.

Measurements

Dry matter presentation yields (DM) and botanical composition before and after grazing were estimated using the 'Comparative Yield Method' of Haydock and Shaw (1975) and the 'Dry-weight-rank Method' of 't Mannetje and Haydock (1963). These measurements were carried out in each grazing cycle during the first, but only in the period of minimum and maximum precipitation in the second and third grazing periods.

In April and August 1992 forage quality and selection by the animals were estimated. Each treatment was sampled on days 1, 4 and 7 of a grazing week for botanical composition and diet selection by four oesophageally-fistulated steers, which had been fasted overnight, between 7 am and 10 am. Two steers were used to graze each paddock for about 20 minutes and an average sample size of 1 kg extrusa was collected from each animal. Samples from the two steers in each paddock were combined and squeezed through muslin cloth. One half of the sample was frozen for later determination of grass leaf and stem, legume, volunteer spp. and dead fractions using the microscope point-hit technique developed by Harker et al.(1964). The other portion of the extrusa was dried at 65 °C for 48 hours, ground through a 1 mm screen and analysed for nitrogen (Kjeldahl) and *in vitro* dry matter digestibility (IVDMD) (Tilley and Terry, 1963).

The animals were weighed after 16 hours overnight fasting with only water after each grazing cycle in the first period and after every two grazing cycles in the second and third period.

Results

Pasture dry matter on offer and botanical composition

The mean DM on offer and botanical composition before grazing are shown in Table 6.1. The main effect on DM yield was caused by SR. There was no significant difference in DM yield between *Bb* and *Bb+Ap* at the LSR, but at the HSR *Ap* had a significant ($P < 0.05$) positive effect on DM yield.

Table 6.1. Mean dry matter on offer (ton DM/ha) and the DW percentages of *B. brizantha (Bb)*, *A. pintoi (Ap)* and other species (OS) measured before grazing from *Bb* grown in monoculture and in association with *Ap* at two stocking rates (LSR = 1.5 AU/ha, HSR = 3.0 AU/ha).

Pasture	SR	DM	DW %		
		(t/ha)	*Bb*	*Ap*	OS
Bb	LSR	6.0a*	95.4a	0c	4.6b
Bb	HSR	3.5c	91.3b	0c	8.7a
Bb + Ap	LSR	6.2a	90.0b	5.9b	4.1b
Bb + Ap	HSR	4.0b	60.6c	34.0a	5.4b

* values within the same column with different letters are significantly ($P < 0.05$) different according to Duncan multiple range test.

The legume content of the mixed pastures was significantly ($P < 0.001$) higher at HSR than at LSR. The pasture was relatively free of weeds ('other species'), with only the HSR of *Bb* showing a significantly higher proportion of 'other species' than the other treatments.

Diet selection

On the sampling dates the dry weight (DW) contribution of *Bb* varied between 75 and 90%, with the exception of *Bb+Ap* at the HSR which averaged 48%. The mean DW contribution of *Ap* at the HSR was 44% whereas that at the LSR was only 8%.

On the first day of the grazing cycle *Bb* leaf comprised between 85 and 95% of the diet in all treatments (Fig. 6.1.), except in *Bb+Ap* at the HSR in which the animals selected *Bb* leaf (42%) and *Ap* (50%). As the plots were grazed down grass leaf content of the diet at the LSR remained high, although it decreased during the grazing week and there was no difference between *Bb* and *Bb+Ap*. At the HSR there was a steep decline in the grass leaf

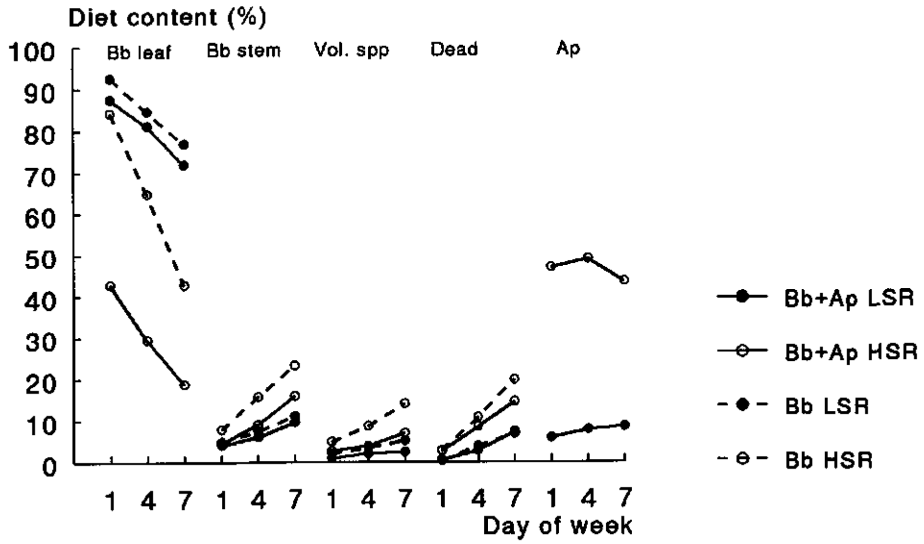

Fig. 6.1. Changes during the week of grazing in the leaf, stem, dead, legume and volunteer spp. content of the diet of cows grazing *B. brizantha* (*Bb*) alone or with *A. pintoi* (*Ap*) grazed at two stocking rates (LSR = 1.5 AU/ha, HSR = 3.0 AU/ha).

content of the diet as the plots were grazed down, with corresponding significant ($P < 0.01$) increases in the content of stem, dead material and volunteer species in the diet. The legume content of the diet was not affected by grazing time, but mean legume content in the diet at the HSR was 6 times higher than that at the LSR.

The CP concentration and IVDMD of the diet significantly ($P < 0.05$) decreased with progressive grazing, but CP% of the diet from *Bb+Ap* stayed above 15% at the HSR. There were no significant differences between *Bb* and *Bb+Ap* in the quality of diet selected at the LSR although CP concentration and IVDMD of the diet were slightly higher for *Bb+Ap*. However, at the HSR *Ap* had a significant positive effect on the CP concentration and IVDMD of the diet selected. On the *Bb+Ap* pasture the mean CP concentration and IVDMD of the diet at the HSR were respectively 8.5 and 4.3 units higher than that selected from *Bb* pasture.

Table 6.2. Changes during the week of grazing in the crude protein concentration (%CP) and *in- vitro* dry matter digestibility (%IVDMD) of the diet of steers grazing *B. brizantha* (*Bb*) in monoculture or with *A. pintoi* (*Bb+Ap*) at two stocking rates (LSR = 1.5 AU/ha, HSR = 3.00 AU/ha).

	LSR		HSR	
	Bb	*Bb + Ap*	*Bb*	*Bb + Ap*
Day		%CP		
1	9.6a*	10.4a	9.5a	17.8a
4	8.7ab	9.4ab	8.0b	16.7ab
7	8.1bc	8.5bc	7.0bc	15.2bc
Mean	8.8	9.4	8.1	16.6
Day		%IVDMD		
1	66.2a	66.0a	62.9a	64.1a
4	63.9ab	64.6ab	58.2b	63.1ab
7	60.5bc	61.8bc	54.1bc	60.9bc
Mean	63.5	64.1	58.4	62.7

* values within the same column with different letters are significantly different ($P < 0.05$) according to Duncan multiple range test.

Table 6.3. Average daily liveweight gain (ADG) of steers grazing *B. brizantha* alone (*Bb*) or with *A. pintoi* (*Bb+Ap*) at two stocking rates (LSR = 1.5 AU/ha, HSR = 3.0 AU/ha).

	LSR		HSR	
Period	*Bb*	*Bb + Ap*	*Bb*	*Bb + Ap*
29.6.90 - 27.2.91	396a*	452a	291a	308a
27.2.91 - 29.1.92	511a	551a	377b	476a
29.1.92 - 24.2.93	449b	515a	345c	501b

* values within the same row with different letters are significantly different ($P < 0.05$) according to Duncan multiple range test.

Liveweight changes

There was a significant effect of sex on average daily liveweight gains (ADG). The mean ADG of steers was 0.05 kg higher than that of heifers. During the first grazing period *Bb+Ap* had higher ADG than *Bb*, but the differences did not reach significance ($P > 0.05$).

During the second grazing period there was a significantly lower ADG on Bb at the HSR than in the other treatments, whilst Bb+Ap showed a significantly higher ADG at the HSR. During the last period there were significant benefits of *Ap* at both SR's.

Cumulative LWG/animal over the three grazing periods together (Fig. 6.2.) clearly show the positive effects of decreasing the SR and of *Ap*. Particularly at the HSR the effect of *Ap* on cumulative LWG/animal was more pronounced in the second and third grazing year, and this was associated with a significant increase in dry matter yields of Ap in the corresponding period.

Table 6.4. Mean annual liveweight gain per animal and per ha on *B. brizantha* alone or grown with *A. pintoi* at two stocking rates (LSR = 1.5 Au/ha, HSR = 3.0 Au/ha), calculated from the data in Fig. 6.2. and 6.3.

	Liveweight gain (kg)			
	per animal		per hectare	
Stocking rate	LSR	HSR	LSR	HSR
Pasture				
B. brizantha	159	119	478	716
B. brizantha + A. pintoi	178	154	534	937
LSD (P = 0.05)	NS	27.4	NS	145

NS = not significant

The cumulative LWG/ha over the three grazing periods together (Fig. 6.3.) shows that *Ap* in the mixture accounted for 30% of the LWG at HSR and for 11% at LSR.

The LWG over the whole period of 1023 days (Fig. 6.2. and 6.3.) have been converted to an annual basis (Table 6.4.). Only at the HSR's were the differences between *Bb* and *Bb+Ap* significant ($P < 0.05$).

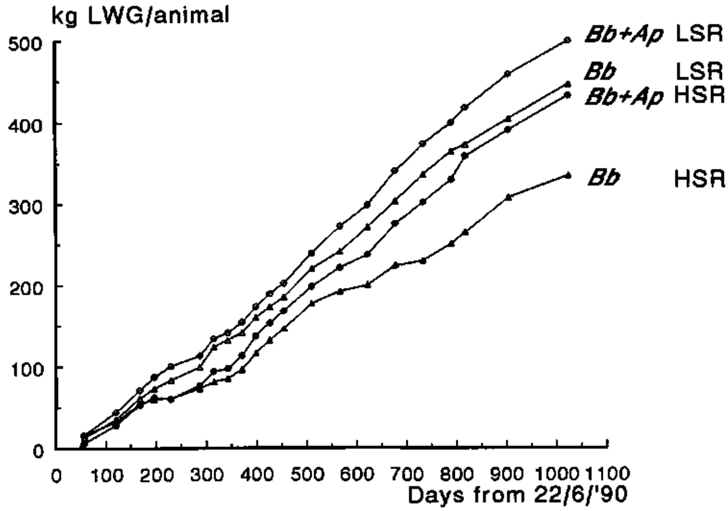

Fig. 6.2. Cumulative liveweight gain (LWG), kg per animal on *B. brizantha* (*Bb*) alone or with *A. pintoi* (*Bb+Ap*) grazed at two stocking rates (1.5 (LSR) and 3.0 (HSR) AU/ha) from 26/6/'90 to 24/2/'93.

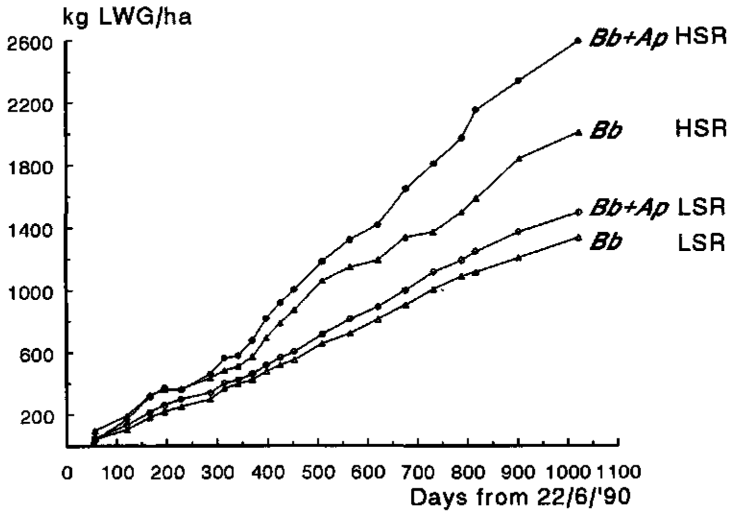

Fig. 6.3. Cumulative liveweight gain (LWG) in kg/ha from *B. brizantha* (*Bb*) alone or with *A. pintoi* (*Bb+Ap*) grazed at two stocking rates (1.5 (LSR) and 3.0 (HSR) AU/ha) from 26/6/'90 to 24/2/'93.

Discussion

Pasture DM production was high (Table 6.1.) and during the 2.8 years of the experiment the pastures maintained a low weed content. The legume content at the HSR was 5.7 times higher than at the LSR. This is in keeping with other findings at "Los Diamantes" (Ibrahim et al., 1993; Ibrahim and 't Mannetje, 1994a). It is rare in tropical grasslands that legume content is increased by increasing SR, although it was also shown by Shaw (1978) with *Stylosanthes humilis* oversown into native pasture in central coastal Queensland, Australia. Practically all reports in the literature show the opposite and most herbaceous legumes are in danger of disappearing with increased stocking rates.

There are few data available on the LWG of cattle on unimproved pastures in the Atlantic Zone of Costa Rica. Gutierrez (1983), reported a liveweight gain of 158 kg/ha/annum at a stocking rate of 1.7 animal/ha, which is regarded as about the optimum stocking rate on unimproved pastures in this zone. The data in Table 6.4. show that *Bb* at the LSR, which was double that of the reported native pasture, produced 300% more than the reported native pasture. The annual LWG/animal of *Bb* at the LSR (159 kg) is comparable to data reported from grass-legume pastures in Queensland, Australia grazed at about half the SR (e.g. 't Mannetje and Jones, 1990). However, observations in the Atlantic Zone indicate that grass only pastures deteriorate in time due to the lack of N input and resultant weed invasion.

The inclusion of *Ap* shows an increased LWG/animal over *Bb* alone and a doubling of the SR had a much smaller effect on the legume based pasture (13% reduction) than on the monoculture (25%). The annual production per ha of *Ap+Bb* grazed at the HSR was nearly six times the amount of the reported production on native pasture.

Experience with *A. pintoi* grown with *Brachiaria dictyoneura* and *B. humidicola* on the acid soils of Carimagua, Colombia, also showed significant improvement in animal production compared to the grass monocultures (CIAT, 1990). With these mixtures stocked at 3 to 4 animals/ha, ADG in the rainy season was 400 to 520 g/day which was 35 to 50% higher than that on the grass monocultures. Annual LWG of *Ap* with *B. dictyoneura* was 400 kg/ha (Lascano, 1993), being 30 to 40% higher than the maximum LWG reported on *Andropogon gayanus/Stylosanthes capitata* and *Brachiaria decumbens/Pueraria phaseoloides* mixtures in Carimagua (Lascano and Estrada, 1989; Lascano and Thomas, 1990). In the present experiment annual LWG of 937 kg/ha was 2.3 times the level of production reported for *Ap* with *B. dictyoneura* above, and this was primarliy associated to a higher carrying capacity of the pasture in this experiment.

On the *Bb* monoculture, the grazing animals selected forage of a higher quality at LSR than at HSR and this is reflected in higher LWG/animal at LSR. The dietary *Bb* leaf levels at LSR was very high and grazing studies with dairy cows in Australia showed that milk yields from *Panicum maximum* pasture was increased as the leaf content in the diet was increased (Stobbs, 1978; Davison et al., 1985). Green leaf fractions are usually of a better quality than stem fractions (Chacon and Stobbs, 1976), and a high leaf content in the diet is responsible for high dry matter intake (Poppi et al., 1981). 't Mannetje (1974) and 't Mannetje and Ebersohn (1980) noted that pasture intake and LWG/animal are related asymptotically to herbage allowance on a DM basis and this may partially explain the difference in LWG between SR's on the grass monoculture, since dry matter yield at the HSR was only 58% that at the LSR.

The results showed unequivocally that *Ap* has a high nutritive value, which was evident from the high quality of diet selected at the HSR. Animals grazing *Bb+Ap* at the HSR selected 45 to 48% of *Ap* in the diet which was similiar to the percentage of *Ap* on offer. This clearly demonstrates that *Ap* has a relatively high selection index when compared to that of *Desmodium ovalifolium* (Toro, 1990; Lascano et al., 1991) and *Stylosanthes guianensis* (Ibrahim and Mannetje, 1994c) and is supportive of the findings of other grazing experiments such as that in which *Ap* was grown with *Bb* and *B. humidicola* in Los Diamantes (Ibrahim and 't Mannetje 1994c) and in which *Ap* was associated with *B. dictyoneura* in Carimagua, Colombia (Lascano and Thomas, 1988; Lascano, 1993). At the HSR *Ap* had a positive effect on the N concentration of the diet, which contributes to increased microbial activity and cellulose digestion in the rumen (Weston and Hogan, 1973; Humphreys, 1991), leading to improved animal performance. Results derived from various experiments with native and grass legume pastures in Australia showed that there was a positive linear increase in LWG per animal over a wide range of N concentrations in the extrusa (Siebert and Hunter, 1977). The IVDMD of the diet selected from *Bb+Ap* at the HSR was also higher than that on the pure grass pasture. This and other studies with *Ap* revealed that IVDMD was higher or similar to the majority of improved grasses and legumes in the Atlantic Zone (Roig, 1989; Heurck, 1990; Ibrahim and 't Mannetje, 1994c).

It is too early to conclude that *Ap* will persist for a long time and that *Bb+Ap* will prove to be a sustainable pasture mixture, but experience over four years are promising. Farmers in the region are also beginning to see the benefits and a few have successfully planted *Bb* and *Ap* for dairy cows in the Atlantic Zone. With a six fold increase in productivity per ha the present total beef production of the Atlantic Zone could be more than doubled by establishing a similarly productive grass-legume pasture as used in this experiment on 25% of the area ('t Mannetje, 1978). It would therefore be possible to both increase beef and milk production in the Atlantic Zone and at the same time make a very large area of land available for other purposes, including reforestation.

Further research is required to find a wider range of grass species to be combined with *Ap* on different soil types. It has been found that *Bb* is subject to a fungal disease on poorly drained soils in The Atlantic Zone of Costa Rica. It is also necessary to investigate SR effects on both the grass-legume balance and the productivity of these pastures. It can be concluded that *Ap* is the best herbaceous legume presently available for the humid tropics, which is capable of maintaining a good proportion of legume with aggressive grasses at high stocking rates and gives high animal production.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

7. GENERAL DISCUSSION AND CONCLUSIONS

The dominant feature of cattle production systems replacing forests in the Atlantic Zone of Costa Rica and in other humid tropical regions is pasture degradation, which is the main factor contributing to the low biological and economic efficiency of extensive and semi-extensive cattle production.

Undoubtedly, the economic and ecological sustainability of cattle raising activities depends to a large extent on pasture sustainability. Intensive pasture management with the use of N fertilizers is generally not recommendable for extensive and semi-intensive cattle rearing in the Atlantic Zone because of low economic efficiency. However, the establishment of persistent grass-legume mixtures under proper management offers one of the best alternatives for increased and sustainable animal production in the humid tropics. Consequently this study was undertaken with the main practical objectives: (1) to identify compatible grass legume mixtures for the Atlantic zone of Costa Rica, (2) to find legumes that are persistent under heavy grazing, (3) to determine the nutritive value of grass legume mixtures and (4) to measure the effect of stocking rate and *Ap* on liveweight gains of beef cattle. Sustainable grass-legume mixtures are based on good establishment and compatibility of the species which must also be persistent under grazing and of a high nutritive value.

The scientific findings of these studies were discussed in the preceding chapters. In this chapter the main findings will be highlighted and their practical significance for animal production in the Atlantic Zone will be discussed. Also, future research needs necessary to further strengthen our knowledge on grass-legume mixtures in this region and for the humid tropics in general will be discussed.

Establishment and Compatibility

The legumes *Cm* and *Sg* established poorly with the semi-erect *Bb,* whereas these species were well established in associations with *Bh*. The results of this and other grazing experiments emphasize the need for selection of appropriate grass species for mixtures with legumes. *Bb* appears to be very aggressive for some legume species and this was also reported in other grazing experiments (Spain et al., 1993).

However, *Ap* established well with both grasses, even though *Ap* establishment was somewhat slower than that of *Cm* and *Sg*. *Ap* is a shade tolerant legume (Ng, 1991; Argel, 1993), which apparently enabled it to establish properly with *Bb*. Shade tolerance of legumes is important, especially since early growth of legumes is slow compared to that of C_4 grasses when water, nutrients and temperature are not limiting and competition for light soon occurs (Ludlow and Wilson, 1970; Torssell et al., 1976). At Los Diamantes soil and climatic conditions favour rapid growth of the C_4 grasses and therefore legume seedlings should have good vigour to compete with the associated grass and invading weeds.

Although *Cm* and *Sg* established well in mixtures with *Bh,* these species did not persist over the 2.5 years of grazing. It should be mentioned that both *Cm* and *Sg* were singled out for being among the most promising legume species for the Atlantic Zone of Costa Rica in cutting experiments at Los Diamantes (CATIE, 1989, 1990; Roig, 1989). However, these species performed poorly under grazing in this experiment and the same was experienced elsewhere. The importance of early screening of herbage species under grazing was discussed by 't Mannetje et al. (1976). Evaluation of herbage species under grazing takes into account the effect of the animal on the pasture including defoliation, recycling of nutrients and soil compaction, all of which can have consequences for persistence of grasses and legumes.

Ap was the most persistent of the three legumes studied but the results of this and other grazing experiments (Grof, 1985; Hurtado, 1988) indicated the need for a strong companion grass for *Ap* as well as proper grazing management. In the absence of a strong companion grass *Ap* may become dominant resulting in unpalatable weeds invading the pasture, possibly as a result of the N accumulated by the legume, as was evident in mixtures with *Bh*. During the second grazing year *Ap* dominated *Bh* especially at the HSR, but over the last six months this mixture was invaded by the aggressive and unpalatable *Paspalum fasciculatum*.

Contrary to this, *Ap* was more or less stable in mixtures with *Bb* and it maintained a more favourable legume balance (22 to 26%) when it was grazed at the HSR (3.00 AU/ha) at the end of the 2.5 years of grazing. Grazing at the LSR reduced the proportion of *Ap* in this mixture, which is contrary to the behaviour of nearly all other tropical legumes. The lower population of *Ap* at the LSR may be associated with lodged stolons of *Bb* which covered the legume.

Over the 2.5 years of grazing *Bh* pastures degraded in time with the invasion of weeds the dominant species being *Paspalum fasciculatum* and *Mimosa pudica*. Degradation of these pastures was caused by the lack of legume persistence in the cases of *Cm* and *Sg*, and the inability of *Bh* to compete with *Ap* and invading weeds. On the other hand *Bb* proved to be an effective barrier against invading weeds which is evident from the low percentages of volunteer species in *Bb* mixtures in spite of the poor establishment of *Cm* and *Sg*. This is of great significance for pasture management in the Atlantic Zone, since weeds are a major problem in this region and herbicides are not only very expensive, but their use also damaging to the environment.

Legume persistence

Cm and *Sg* are climatically well adapted in the Atlantic Zone of Costa Rica, but they lack mechanisms for persistence under grazing. *Cm* did not flower in the experimental plots, which is one of the main weaknesses of this legume. Apart from this, grazing was found to be detrimental on stolon and root development of *Cm*, in spite of good soil moisture conditions for vegetative perennation of this species. The rapid disappearance of *Cm* and *Sg* may be associated with frequent defoliation of the regenerative tissues. Generally, legumes that are prostrate and those that have an abundance of regenerative buds are more persistent under grazing than those of twining and erect growth forms which exposes the growing points to defoliation (Clements, 1986). This may partially explain the better persistence of *Ap* compared to *Cm* and *Sg* in this experiment.

Apart from its prostrate growth habit, *Ap* possesses several attributes that are required for persistence and this was also found in other grazing experiments with *Ap* (Grof, 1985; Argel, 1993; Jones, 1993). This species has the ability to flower and set seed all year round, which resulted in a rapid build up of seed reserves. Besides, the high stolon and rooting density of *Ap* signifies that it can persist by vegetative perennation in this environment.

It should be pointed out that only a few legumes like *Ap* are capable of strong perenniality by both sexual and vegetative pathways. The ability of *Ap* to build up seed reserves in combination with its strong ability to perennate vegetatively makes this species very resilient to catastrophic events leading to a sudden set back in its growth or plant population, such as may occur with unseasonal droughts or outbreaks of pest or diseases.

The results of this and other studies (Hurtado, 1988; Hernandez et al., Chapter 6 of this thesis) showed that *Ap* was tolerant to heavy grazing which is rare for tropical legumes. In humid environments most tropical legumes are unable to persist at stocking rates above 1.5 AU/ha (Humphreys, 1980; Hurtado, 1988), as was also observed with *Cm* and *Sg* in this study. The ability of *Ap* to tolerate heavy grazing is of great significance for animal production and for pasture sustainability. In some years heavy grazing may be unavoidable, because of the need to increase animal numbers to generate more farm income, or the loss of markets so that animals cannot be sold and in the event of drought.

As mentioned previously, *Sg* is among the strongest *Stylosanthes* spp., but conditions at Los Diamantes probably did not favour this legume. Apart from this, *Sg* is short-lived and this may also explain the reason for its poor persistence in this study. Longer-lived *Stylosanthes* populations will have more chance to an adequate build up of seed reserves which is important to ensure seedling recruitment. In addition, a higher population of *Sg* means that individual plants will be defoliated less frequently, thereby enhancing longevity of this species. Frequent grazing of individual plants does not only reduce the life span of the plants, but it is also damaging for flowering and seed production which are of vital importance for perennality of most legume species.

Pasture and animal productivity

In the Atlantic Zone of Costa Rica there is a great potential for forage production, which is evident from the high DM yields over the 2.5 years of grazing. *Bb* produced more than 19 t DM/ha at the HSR (3.00 AU/ha), which is considerably more than that produced by the main grass species in this region (CATIE, 1989, 1990; Veldkamp, 1993). Experience with *Bb* in other environments also showed that this grass was highly productive under heavy grazing (Grof, 1985; CIAT, 1990).

However, the disappearance of *Cm* and *Sg* in mixtures with *Bb* could have severe consequences for long term pasture productivity if no other legumes were available. Experience with unfertilized improved pastures (*Panicum maximum*, *Hypharrenhia rufa*, *Cynodon nlemfuensis* etc.) without persistent legumes showed that these pastures were not sustainable over a long period, mainly because of depletion in soil fertility with time (Toledo and Ara, 1977; Toledo and Mendoza, 1989; Toledo, 1993).

The results of this study showed that *Ap* was capable of fixing more than 100 kg N/ha at the HSR which is of importance for sustainability of this mixture. N is one of the most important elements for growth of grasses and there is evidence that exotic grasses require N in order to persist in competition with indigenous or naturalised grasses ('t Mannetje and Shaw, 1972; Henzell et al., 1975). However, the calculated amount of N fixed by *Ap* was lower than could have been expected, which was probably caused by the relatively high soil fertility at this experimental site.

The nutritive value of *Bb, Bh* and *Ap* was characterised by higher CP and IVDMD than those reported for other grass and legume species in the Atlantic Zone (CATIE, 1989, 1990; Roig, 1989). CP of the grasses was never below 10% and this is of vital importance when it is considered that the CP value of most tropical grasses frequently falls below 7% (Wilson and Minson, 1980), resulting in heavy losses of liveweight.

Liveweight gain per ha of animals grazing pure *Bb* (478 kg/ha) was three times that reported from native pastures (158 kg/ha) in this region (Gutiérrez, 1983), demonstrating the high potential of improved grasses for increased animal production. However, the liveweight gains were doubled again with the inclusion of *Ap*. At the HSR (3.00 AU/ha) the measured annual liveweight gain of 937 kg/ha which was achieved with *Bb+Ap* is exceedingly high when compared to liveweight gains reported for other improved legume based pastures ('t Mannetje, 1982; Dextre et al., 1987; CIAT, 1989). *Ap* is of a high quality and it has a good selection index, both of which were responsible for higher liveweight gains when animals graze the association.

The high DM yields and animal productivity obtained in these studies have several implications for animal production in the Atlantic Zone. Firstly, the stocking rate of the pastures can be increased from 1 to about 3 AU/ha with the introduction of the *Bb+Ap* mixture and this together with high animal productivity will ensure increased economic efficiency of cattle production in the region. With present market prices for non livestock agricultural commodities being low, sustainable pasture improvement, along the lines advocated in this study, will make livestock even more competitive with other agricultural sectors in the Atlantic Zone of Costa Rica.

However, for this technology to be applicable on a large scale some development will be necessary. This would consist of seed production of legumes and grasses, a commercial infrastructure for the distribution of seeds and a credit system to allow farmers to borrow money for the development.

Environmental impact

The six fold animal production increase possible from the introduction of sustainable grass-legume mixtures means that the present cattle production in the Atlantic Zone could be doubled by introducing such mixtures to 25% of the area ('t Mannetje, 1978). This has a number of consequences in relation to the environment. Firstly, this greatly increased production could be practised on a reduced area, thereby making more land available for reforestation. Secondly, this production increase can be obtained with low input technology. On the fertile soils of the region no fertilizers would be required at all and on the infertile soils only some superphosphate would be advisable for increased sustainability. Well managed pastures require no crop protection measures.

Also in relation to the concern of the release of CO_2 to the atmosphere after deforestation highly productive sustainable grass-legume mixtures have a contribution to make. As Veldkamp (1993) has pointed out, unimproved grassland establishment after deforestation has lead to losses of between 1.5 Mg C/ha and 21.8 Mg C/ha over twenty five years. However, in modelling studies based on experimentation, Veldkamp (1993) also found that CO_2 losses after deforestation and pasture establishment with the unproductive *Axonopus compressus* amounting to between 31.5 and 60.5 Mg C/ha could be reduced to between 12.0 and 24.7 Mg C/ha when a selected improved grass (*Brachiaria dictyoneura*) would be used to establish pastures. The present studies have shown that the inclusion of a legume in improved pastures further increases DM accumulation as a result of the N contribution of the legume and the amount of TOC measured averaged 47 t/ha, which compares favourably with the 48 t/ha measured by Veldkamp (1993) under rain forest in the Atlantic Zone of Costa Rica.

The main stores of C on earth are the ocean, forests, rangelands and grasslands, with probably little difference between forests on the one hand and grasslands plus rangelands on the other (Goudriaan, 1990). Therefore, it is both environmentally and agriculturally beneficial to promote the use of sustainable grass-legume mixtures with proper management.

The fear of severe soil compaction under grazing was not sustained in this study. Heavy grazing (3.0 AU/ha) over three years resulted in a slight increase in soil bulk density, but the value was still only around 0.8 g/cm^3, which is low compared to average bulk densities measured in The Netherlands (1.4 g/cm^3). It was suggested that the high accumulation of organic matter under grass-legume pastures would reduce the compaction from animal treading.

Negative environmental effects to be expected from pasture improvement using grass-legume mixtures to be considered are CH_4, NH_3 and N_2O emissions. CH_4 emissions to the atmosphere arise largely from natural anaerobic ecosystems such as paddy rice fields and fermentative digestion systems of ruminants. In grasslands CH_4 is produced by the grazing animals and by a proportion of the faecal materials decomposing anaerobically (Leng, 1993). Rumen micro-organisms ferment feed to volatile fatty acids with CH_4 and CO_2 as by-products. A proportionally larger part of the metabolizable energy intake of ruminants is transformed into CH_4 from poor quality feed (15 - 18 %), such as that produced by unimproved grasslands compared to high quality feed (7 %) such as perennial ryegrass (*Lolium perenne*) (Leng, 1993). The quality of the *Bb* + *Ap* mixture is not as good as that of *L. perenne*, but an improvement on unimproved pastures.

NH_3 volatilization takes place from dung and urine of cattle. N_2O emissions occur in the processes of nitrification and denitrification. There are no known studies on these processes in humid tropical pastures, but it is likely that NH_3 volatilization and denitrification would occur under these humid warm conditions. However, the amount of NH_3 and NO^-_3 available for volatilization and denitrification depends on the amount of N and thus on that of legume in the system. The measured N fixation for *Ap* of around 100 kg/ha in these studies would not lead to more than 10 kg/ha/year of NH_3-N being volatilised and no more than 10 kg/ha/year NO^-_3-N denitrified, of which no more than 5% would consist of N_2O ('t Mannetje and Jarvis, 1990).

Summarising, the environmental impact of legume based pasture improvement in the Atlantic Zone of Costa Rica would be positive.

Future research needs

Although a low input technology has been developed for the Atlantic Zone of Costa Rica, experience with *Bb* + *Ap* is not of long enough duration to claim long term sustainability. It is therefore important to continue monitoring the persistence and productivity of this mixture both in experiments and on practical farms that are now starting to adopt this technology.

At the same time, it is dangerous to rely entirely on one grass and one legume. There is always the danger of a disease or pest to develop which can lead to the demise of one or both components of the mixture. This has occurred with other successful legumes such as *Leucaena leucocephala* (psyllids) (Bray and Woodroff, 1988) *Stylosanthes* (anthracnose disease) (Davis et al.,1987) and *Macroptilium atropurpureum* (rust) (Bray, 1988)

Although *Bb* has proved to be productive on the well drained and moderately well drained soils in the Atlantic Zone, it has been observed to develop a fungus disease when grown on poorly drained soils.

For these reasons, applied research on experimental stations and on farms needs to be carried out to select more grazing tolerant legumes and grasses which are compatible, persistent and productive.

There is a need for more detailed ecological research on the competition between *Ap* and grasses under grazing to increase our understanding of *Ap* behaviour in relation to establishment and in mixtures with grasses. From the latter strategies should then be developed for the manipulation of the grass-legume balance in mixtures under grazing.

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SUMMARY

Cattle production in the Atlantic Zone of Costa Rica has assumed a prominent role in the occupation of frontier lands and has been regarded as a major contributor to deforestation.

In the Atlantic Zone of Costa Rica more than 70% of pastures are dominated by low yielding unproductive grasses of low quality, which is the main cause for low animal production in the region. However, high quality grasses and legumes which fix substantial amounts of N, used in mixtures offer the best low-input technology for sustainable forage production. In order to increase knowledge and understanding of grass-legume mixture behaviour, a study was conducted with the main objective to identify compatible grass-legume mixtures that are persistent and of a high nutritive value. In addition, liveweight gains were measured in a supplementary experiment.

Materials and Methods

A field experiment was conducted between September 1989 and October 1992 at the "Los Diamantes" research station at Guápiles in the Atlantic Zone of Costa Rica, with a mean annual rainfall of 4332 mm and mean temperature of 24.6 °C. The soil is a well drained loamy Eutric Hapludand or Umbric Andosol of medium to high fertility, with a mean pH-H_2O of 5.8 and available phosphorus (Olsen) of 7 ppm.

The treatments consisted of a factorial of three legumes of contrasting growth habit (*Centrosema macrocarpum (Cm)* CIAT 5713, *Stylosanthes guianensis (Sg)* CIAT 184 and *Arachis pintoi (Ap)* CIAT 17434), two grasses of different growth habit (*Brachiaria brizantha (Bb)* CIAT 6780 and *Brachiaria humidicola (Bh)* CIAT 6339) and two stocking rates (1.75 (LSR) and 3.00 (HSR) AU/ha) both of which are higher than the average stocking rate (SR) of the region. There were two replicates for each treatment. Grazing was initiated in January 1990 using a rotational cycle of 5 days grazing and 30 days resting.

Botanical composition and forage dry matter (DM) on offer were measured before and after each grazing cycle. Annual DM production was calculated assuming linear growth rates during the grazing period.

The number of *Ap* flowers/m^2 was recorded monthly, while for *Sg* the number of reproductive units (flowers + pods)/m^2 was counted at peak flowering (September -

November), but only in the *Bh* association. In each plot 100 original legume plants were tagged to determine survival rates and the same was done with new cohorts of *Ap* and of *Sg* (for the latter only in association with *Bh*). Plant and seedling densities of all legumes as well as stolon and rooting characteristics of *Ap* and *Cm* were recorded frequently.

Hand-plucked samples of the grasses and legumes were collected every two grazing cycles in all treatments for the determination of *in vitro* dry matter digestibility (IVDMD) (Tilley and Terry, 1963) and crude protein concentration (% CP). The botanical composition and quality of the diet selected was measured with five steers fistulated at the oesophagus (OF) on three dates with *Cm* and *Sg* in the *Bh* association and on six dates for all *Ap* treatments, starting in May 1991. Botanical composition of the diet was determined by the method of Heady and Torrel (1959). Diet samples collected were also analyzed for CP and IVDMD.

Soil samples were taken at 10 cm depth from *Cm* and *Ap* treatments at the end of the 2.5 years of grazing for analysis of the organic matter content (%SOM) and total nitrogen concentration (% N). In addition, bulk densities were measured at three sampling depths (0-5, 5-10 and 10-15 cm) using 100 cm^3 cylinders. Total organic carbon (TOC, t/ha) and total soil nitrogen (TSN, t/ha) were estimated taking into account bulk density and sampling depth. In a supplementary experiment liveweight gains (LWG) were measured on *Bb* and *Bb*+*Ap* at two stocking rates (1.5 AU/ha and 3.0 AU/ha).

Results

Dry matter yields and botanical composition

Mean DM yield on offer over treatments was always above 4 t/ha, but it significantly decreased during the drier months (Chapter 2). DM yield on offer increased in time, which was associated with a higher contribution of sown grasses. DM yields were significantly higher at the LSR than at the HSR and *Bb* had significantly higher DM yields than *Bh*. There was little effect of legume species on DM on offer in *Bb* mixtures, but with *Bh* mean DM yield was lowest for *Cm*.

Bb maintained high dry weight percentages in all treatments, but *Bh* began to be replaced by volunteer species after the first year. *Cm* and *Sg* only performed well in the first year in association with *Bh*. *Cm* had virtually disappeared by the second year in all treatments, whilst *Sg* persisted to some extent with *Bh* at the LSR only. In contrast *Ap* was very persistent, especially at the HSR. It formed a balanced mixture with *Bb* at the HSR, but it replaced *Bh* and towards the end of the experimental period there was a massive invasion of weeds in the *Bh* treatments. Total above ground N yield of *Ap* mixtures was significantly higher than that of *Cm* mixtures. This was mainly due to a significant contribution of *Ap* to total above ground N yield.

Persistence

Cm only flowered out of reach of the animals (Chapter 3). *Sg* flowered profusely between September and November but the number of reproductive units per m^2 decreased linearly in time. Seed reserves of *Sg* were higher at LSR than at HSR, but also decreased in time. On the other hand, *Ap* flowered all year round, although the number of flowers/m^2 decreased during the short days (November - March). This resulted in a high build up of seed reserves of *Ap*. The number of *Ap* flowers and seeds/m^2 was significantly higher at the HSR and in association with *Bh*.

There was no effect of SR on death rates of the original legume populations, except for *Sg* which had significantly higher death rates at the HSR than at the LSR in the *Bh* mixture. There were no effects of grass species on longevity of the legumes. The mean half-life of the original legume populations was 8.0, 10.2 and 26.7 months for *Cm, Sg* and *Ap*, respectively. The mean half-life of the populations of *Ap* seedlings was 14 months and that of *Sg* seedlings 7 months.

The plant densities of *Cm* and *Sg* decreased with time. Plant and seedling density of *Sg* at the LSR was higher than of the HSR, but not adequate to maintain a desired density of *Sg*. Contrary to this, the population of *Ap* significantly increased in all mixtures. Plant density of *Ap* was higher in *Bh* mixtures and at the HSR. The increase in plant density of *Ap* was associated with continuous seedling recruitment.

Grazing had deleterious effects on stolon density and rooting characteristics of *Cm*. In the *Bh* association the mean number of rooted stolons/m^2 was 28.3, 14.0 and 1.4 in June 1990, January 1991 and June 1991, respectively. In contrast the mean stolon and rooting density of *Ap* increased significantly in time. Stolon length of *Ap* at the end of grazing ranged from 50 to 117 m/m^2, depending on the population of *Ap* in the various treatments.

Quality

Mean IVDMD of the hand-plucked green material of the sown grasses was 65% (range

63.7 to 66.6%) and there were no significant differences in IVDMD between *Bb* and *Bh* (Chapter 4). IVDMD at the HSR was significantly higher than at the LSR, but differences were small (1.6 to 2.2 units). Mean CP of hand-plucked samples of the grasses was 11.8% and CP concentration at the HSR was 0.4 to 0.9 units higher than of the LSR. In time the CP% of the grasses tended to decrease in mixtures with *Cm* and *Sg*, while the reverse was observed for *Ap*. The quality of the hand-plucked grass material decreased in the drier months.

There was no significant effect of grass species on quality of the legumes. CP of hand-plucked legume material was high (*Ap* 23.9%, *Cm* 23.6% *Sg* 20.5%). The mean IVDMD of hand-plucked *Ap* (65.7%) was 7.5 units higher than that of *Cm* and *Sg*. There was no significant effect of SR on IVDMD of *Ap* and *Sg*, but mean IVDMD of *Cm* at the LSR was significantly lower than at the HSR, although the difference was only 1.5 units. There was also a marked seasonal variation in IVDMD and CP of the hand-plucked green material, but IVDMD of *Ap* remained above 65% in the drier months while that of *Cm* and *Sg* fell below 56%. During the flowering period CP and IVDMD of *Sg* fell abruptly, and this was probably associated with a higher percentage of stem material in the hand-plucked samples.

The selection index (SI) of *Sg* was lower than that of *Cm* and *Ap*. In all mixtures SI of *Ap* was above 1, indicating positive selection for this legume. The OF steers selected a high percentage of green leaf material and a small proportion of stem and dead material. Volunteer species did not form a significant percentage of the diet, except for *Bh* + *Cm* at the LSR. As the *Ap* plots were grazed down during the grazing period, the percentage of stem and dead material in the diet increased, but green leaf material remained high.

Mean IVDMD of the diet selected ranged from 62.4 to 65.8% and CP ranged from 11.4 to 16.5%. IVDMD of the diet at the LSR was higher than that at the HSR (2.1 to 4.5 units). The CP concentration of the diet selected from *Ap* mixtures was relatively high and it varied between 13.1 and 17.8%. There was a positive relationship between the CP % of the diet selected from *Ap* mixtures and the amount of *Ap* in the diet. As the *Ap* plots were grazed down during the grazing period, IVDMD and CP of the diet decreased, but they still remained relatively high up to the end.

Soil fertility and bulk density

Mean SOM was 9.1% and mean TOC was 47.2 t/ha (Chapter 5). These were not significantly affected by mixtures, but SOM and TOC at the LSR was significantly higher than at the HSR, although the differences were relatively small. Mean total N concentration varied between 0.428 and 0.482% and it was higher for *Ap* than for *Cm* mixtures. *Ap* fixed about 120 kg N/ha/year in association with *Bb* at the HSR.

Over the 2.5 years of grazing there was no evidence of a great degree of soil compaction. Bulk density was never above 1.0 g/cm^3 which is relatively low compared to values reported from elsewhere. Bulk densities were lower in *Ap* than in *Cm* mixtures and this may be associated to high stolon and rooting density of *Ap*.

Liveweight gains

Liveweight gain on pure *Bb* pastures was 478 kg/ha and this was three times that reported on native pastures in the Atlantic zone of Costa Rica (Chapter 6). Mean annual liveweight gain of *Bb* + *Ap* was 937 kg/ha at the HSR, which was significantly higher than that of *Bb* monoculture and superior to values reported for grass- legume mixtures elsewhere.

Environmental impact

With the six fold increase in liveweight gain that is possible with the inclusion of *Bb* + *Ap*, the beef production in the Atlantic Zone could be doubled if only 25% of the present area under pasture would be improved with that or a similar mixture. This means that more land could be made available for reforestation. In addition, the carbon storage of such improved pastures would also contribute to reduced CO_2 emission to the atmosphere. The negative impact of pasture improvement consists of soil compaction, CH_4 and N_2O emissions, but it was argued that these effects were not significant.

Future research

Future research should be concentrated on finding other suitable grasses and legumes to compliment the *Bb* + *Ap* mixture presently available because of the danger of failure of improved pastures if something should happen to one of the components of the mixture. There is also a need for ecological research to study competitive relations of *Ap* with grasses to improve establishment and to learn how to manipulate the grass legume balance by grazing management.

Conclusions

Over the 2.5 years of grazing *Ap* formed a good mixture with *Bb* at the HSR. *Ap* has several attributes required for persistence and this should result in long term sustainability of mixtures with a suitable companion grass grazed at the right SR.

Cm and *Sg* failed to persist over the 2.5 years of grazing, which was caused by a combination of lack of grazing tolerance, a short life-span and inability to produce sufficient seed to secure plant replacement.

The nutritive value of *Bb, Bh* and *Ap* was characterised by higher CP and IVDMD than those reported for other grasses and legumes in the Atlantic zone of Costa Rica.

SAMENVATTING

Veeteelt neemt een prominente plaats in in de recent ontgonnen gebieden in de Atlantische Zone van Costa Rica en wordt beschouwd als een belangrijke reden van ontbossing. In dit gebied wordt meer dan 70% van de graslanden gedomineerd door laag produktieve grassen met een geringe voederwaarde, waardoor de veeproduktie laag is. Mengsels van goede grassen en leguminosen die stikstof binden, bieden de beste *low input* technologie voor duurzame voederproduktie. Ten einde de kennis over en het inzicht in het gedrag van gras-leguminosenmengsels te vergroten werd onderzoek uitgevoerd met als voornaamste doelstellingen om grassen en leguminosen te vinden die bij elkaar passen, die standvastig zijn en een hoge voederwaarde bezitten. Bovendien werd de gewichtstoename van runderen gemeten in een aansluitende proef.

Materiaal en methoden

Een veldproef werd uitgevoerd van september 1989 tot oktober 1992 op het "Los Diamantes" onderzoekcentrum in Guápiles in de Atlantische Zone van Costa Rica met een gemiddelde regenval van 4332 mm per jaar en een gemiddelde temperatuur van 24,6 °C. De bodem is een goed doorlatende zavelachtige Eutric Hapludand of Umbric Andosol van gemiddelde tot hoge vruchtbaarheid, met een pH-H_2O van 5,8 en beschikbare phosphorgehalte (Olsen) van 7 dpm.

De behandelingen bestonden uit een factorial van drie leguminosen met verschillende groeivorm (*Centrosema macrocarpum (Cm)* CIAT 5713, *Stylosanthes guinanensis (Sg)* CIAT 184 en *Arachis pintoi (Ap)* CIAT 17434, twee grassoorten met verschillende groeivorm (*Brachiaria brizantha (Bb)* CIAT 6780 en *B. humidicola (Bh)* CIAT 6339 en twee beweidingsdichtheden (1,75 (LSR) en 3,00 (HSR) GVE/ha), die beiden hoger zijn dan de gebruikelijke veedichtheid in dit gebied. Er waren twee herhalingen. Beweiding begon in januari 1990 op basis van een omweidingssysteem met een cyclus van 5 dagen beweiden en 30 dagen rust.

De botanische samenstelling en ruwvoeder droge-stofopbrengst werden bepaald voor en na iedere beweidingsperiode. Jaarlijkse droge-stofopbrengst werd berekend door een lineaire groei gedurende beweiding aan te nemen.

Het aantal bloemen/m^2 van *Ap* werd maandelijks en het aantal bloemen plus peulen/m^2 van

Sg werd gedurende de maximale bloeiperiode (september - november) geteld. In elk perceel werden 100 originele leguminosenplanten gemerkt om overleving te bepalen en hetzelfde werd gedaan voor nieuwe cohorten van *Ap* en *Sg* (voor de laatst genoemde alleen in mengsels met *Bh*). Dichtheden van planten en kiemplanten van alle leguminosen en stolon- en bewortelingseigenschappen van *Ap* en *Cm* werden veelvuldig bepaald.

Hand-geplukte monsters van de grassen en leguminosen werden elke tweede beweidingscyclus verzameld in alle behandelingen voor de bepaling van *in vitro* verteerbaarheid (IVDMD) (Tilley en Terry, 1963) en ruw eiwit (CP). De botanische samenstelling en kwaliteit van het geselecteerde dieet werden gemeten met behulp van vijf ossen met een slokdarmfistel op drie data voor *Cm* en *Sg* en op zes data voor alle *Ap* behandelingen vanaf mei 1991. De botanische samenstelling van het dieet werd bepaald volgens de methode van Heady en Torrel (1959). Dieet monsters werden ook geanalyseerd voor CP en IVDMD.

Bodemmonsters werden genomen tot 10 cm diepte in *Cm* en *Ap* behandelingen aan het eind van 2,5 jaar beweiding voor de bepaling van het organische-stofgehalte (%SOM) en totale-stikstofgehalte (%N). Bovendien werd de bodemdichtheid (*bulk density*) op drie diepten (0-5, 5-10 en 10-15 cm) gemeten met 100 cm^3 cilinders. Totale koolstof (TOC, t/ha) en totale stikstof (TSN, t/ha) werden geschat met in acht neming van bodemdichtheid bemonsteringsdiepte.

Resultaten

Ruwvoeder droge-stofopbrengst en botanische samenstelling

De gemiddelde droge-stofopbrengst voor beweiding was altijd hoger dan 4 t/ha, maar het nam significant af gedurende de drogere tijd (Hoofdstuk 2). De droge-stofopbrengst voor beweiding nam toe in de tijd, hetgeen samen hing met de grotere bijdrage van de ingezaaide grassen. Droge-stofopbrengsten waren significant hoger bij LSR dan bij HSR en *Bb* had significant hogere droge-stofopbrengsten dan *Bh*. Er was weinig invloed van de leguminosensoort op de droge-stofopbrengst in *Bb* mengsels, maar voor *Bh* was de gemiddelde opbrengst het laagst met *Cm*.

Bb behield hoge drooggewichtsprocenten in alle behandelingen, maar *Bh* werd vanaf het tweede jaar vervangen door onkruiden. *Cm* en *Sg* deden het alleen goed in het eerste jaar met *Bh*. *Cm* was praktisch verdwenen uit alle behandeling voor het einde van het eerste jaar, terwijl *Sg* alleen enige standvastigheid toonde met *Bh* bij LSR. *Ap* daarentegen was zeer standvastig, vooral bij HSR. Het vormde een gebalanceerd mengsel met *Bb* bij HSR, maar het verving *Bh* en tegen het einde van de proefperiode was er een enorme invasie van onkruiden in de *Bh* behandelingen.

De totale bovengrondse stikstofopbrengst van de *Ap* mengsels was significant hoger dan dat van de *Cm* mengsels. Dit was voornamelijk het gevolg van een belangrijke bijdrage van *Ap* tot de totale bovengrondse stikstofopbrengst.

Standvastigheid

Cm bloeide alleen waar het buiten het bereik van de dieren was (Hoofdstuk 3). *Sg* bloeide op grote schaal tussen september en november maar het aantal bloemen plus peulen per m^2 nam rechtlijnig in de tijd af. Zaadreserves van *Sg* waren hoger bij LSR dan bij HSR, maar namen in de tijd ook af. Daarentegen bloeide *Ap* het hele jaar door, alhoewel het aantal bloemen/m^2 afnam gedurende de korte dagen (november-maart). Dit resulteerde in een grote opbouw van zaadreserves van *Ap*. Het aantal *Ap* bloemen/m^2 was significant hoger bij de HSR en in associatie met *Bh*.

Er was geen effect van beweidingsdichtheid op de afstervingssnelheid van de originele leguminosenpopulaties, behalve voor *Sg*, waar de afstervingssnelheid significant hoger was bij HSR dan bij LSR in het *Bh* mengsel. Er was geen effect van grassoort op de levensduur van de leguminosen. Het half-leven van de originele leguminosenpopulaties was 8,0, 10,2 en 26,7 maanden voor respectievelijk *Cm, Sg* en *Ap*. Het gemiddelde half-leven van kiemplantenpopulaties van *Ap* was 14 maanden en dat van *Sg* kiemplanten 7 maanden.

De plantdichtheden van *Cm* en *Sg* namen af in de tijd. Plant- en kiemplantdichtheden van *Sg* waren hoger bij LSR dan bij HSR, maar onvoldoende om een gewenste dichtheid van *Sg* te behouden. In tegenstelling hiermee nam de populatie van *Ap* significant toe in alle mengsels. Plantdichtheid van *Ap* was groter in *Bh* mengsels en bij de HSR. De toename van *Ap* plantdichtheid hing samen met voortdurende recrutering van kiemplanten.

Beweiding was schadelijk voor de stolondichtheid en beworteling op de knopen van *Cm*. In het mengsel met *Bh* nam het gemiddelde aantal bewortelde *Cm* stolonen af van 28,3 in juni 1990 tot 14,0 in januari 1991 en tot 1,4 in juni 1991. In tegenstelling daarmee namen de gemiddelde stolonen- en bewortelingsdichtheid van *Ap* significant toe. De stolonlengte van *Ap* aan het einde van de proefperiode varieerde van 50 tot 117 m/m^2, afhankelijk van de populatie van *Ap* in de verschillende behandelingen.

Kwaliteit

De gemiddelde IVDMD van de hand-geplukte monsters van de ingezaaide grassen was 65% (spreiding 63,7 tot 66,6%) en er waren geen significante verschillen tussen *Bb* en *Bh* (Hoofdstuk 4). IVDMD was significant hoger bij HSR dan bij LSR, maar de verschillen waren slechts gering (1,6 tot 2,2 eenheden). Het gemiddelde CP van hand-geplukte monsters van de grassen was 11,8 en het CP bij de HSR was 0,4 tot 0,9 eenheden hoger dan bij LSR. Met de tijd nam het CP% van de grassen af in mengsels met *Cm* en *Sg*, terwijl het omgekeerde het geval was voor *Ap*. De kwaliteit van de hand-geplukte monsters nam af in de drogere maanden.

Er was geen significant verschil van grassoort op de kwaliteit van de leguminosen. CP van de hand-geplukte monsters van leguminosen was hoog (*Ap* 23,9%, *Cm* 23,6% en *Sg* 20,5%). Het gemiddelde IVDMD van hand-geplukte *Ap* (65,7%) was 7,5 eenheden hoger dan dat van *Cm* en *Sg*. Er was geen significant effect van beweidingsdichtheid op IVDMD van *Ap* en *Sg*, maar het gemiddelde IVDMD van *Cm* bij LSR was significant lager dan bij HSR, alhoewel het verschil slechts 1,5 eenheden bedroeg. Er was ook een duidelijk seizoensvariatie in IVDMD en CP van de hand-geplukte monsters van groen materiaal, maar het IVDMD van *Ap* bleef boven de 65% in de drogere maanden, terwijl dat van *Cm* en *Sg* tot beneden 56% daalde. Gedurende de bloeitijd van *Sg* daalde het CP en IVDMD abrupt en dit hing waarschijnlijk samen met een hoger percentage stengel in de hand-geplukte monsters.

De selectie-index (SI) van *Sg* was lager dan dat van *Cm* en *Ap*. In alle mengsels was de SI van *Ap* > 1, hetgeen aangeeft dat er positieve selectie was voor deze leguminoos. De slokdarmfistelstieren selecteerden een hoog percentage groen blad en een kleine hoeveelheid stengel en dood materiaal. Onkruiden vormden geen belangrijk percentage van het dieet, behalve voor *Bh* + *Cm* bij LSR. Met het afgrazen van de *Ap* percelen gedurende de beweidingsperiode nam het aandeel stengel en dood materiaal in het dieet toe, maar de hoeveelheid groen blad bleef hoog.

De gemiddelde IVDMD in het dieet varieerde van 62,4 tot 65,8% en CP varieerde van 11,4 tot 16,5. IVDMD van het dieet bij LSR was hoger dan dat bij HSR (2,1 tot 4,5 eenheden). De CP concentratie van het dieet in *Ap* mengsels was betrekkelijk hoog en varieerde van 13,1 tot 17,8%. Er was een positieve relatie tussen CP% en in het dieet van

Ap mengsels en de hoeveelheid *Ap* in het dieet. Met het afgrazen van de *Ap* percelen gedurende de beweidingsperiode namen IVDMD en CP af, maar zij bleven relatief hoog tot aan het einde.

Bodemvruchtbaarheid en bodemdichtheid

De gemiddelde SOM was 9,1% en de gemiddelde TOC 47,2 t/ha (Hoofdstuk 5). Deze hoeveelheden werden niet significant beïnvloed door de mengsels, maar SOM en TOC waren significant hoger bij LSR dan bij HSR, alhoewel de verschillen relatief klein waren. De gemiddelde totale stikstofconcentratie varieerde van 0.428 tot 0.482% en het was hoger voor *Ap* dan voor *Cm* mengsels. *Ap* fixeerde ongeveer 120 kg N/ha/jaar in associatie met *Bb* bij HSR.

Gedurende de 2,5 jaar van beweiding was er geen aanwijzing van grote bodemverdichting. De bodemdichtheid was nooit hoger dan 1,0 g/cm^3, hetgeen relatief laag is in vergelijking met waarnemingen elders. Bodemdichtheden waren lager voor *Ap* dan voor *Cm* mengsels en dit hangt waarschijnlijk samen met de grote stolonen- en bewortelingsdichtheid van *Ap*.

Gewichtstoename van het vee

De gewichtstoename van de dieren op pure *Bb* percelen was 478 kg/ha/jaar en dit was drie keer zoveel als op onverbeterd grasland in de Atlantische Zone van Costa Rica (Hoofdstuk 6). De gemiddelde gewichtstoename op *Bb* + *Ap* was 937 kg/ha/jaar bij HSR en dit was significant hoger dan dat van de monocultuur van *Bb* en hoger dan andere gepubliceerde waarden van andere gras-leguminosen mengsels elders.

Invloed op het milieu

Met de zesvoudige gewichtstoename die mogelijk is door de toepassing van het *Bb* + *Ap* mengsel kan de veeproduktie in Atlantische Zone worden verdubbeld door slechts 25% van het totale areaal dat nu als grasland wordt gebruikt te verbeteren met dit of een ander geschikt mengsel. Dit betekent dat meer land beschikbaar zou komen voor herbebossing. Bovendien zou de koolstofopslag van dergelijke verbeterde graslanden bijdragen tot de vermindering van CO_2 emissies naar de atmosfeer. De negatieve invloed van verbeterd grasland op het milieu bestaat uit bodemverdichting, CH_4 en N_2O emissies, maar het wordt aangetoond deze effecten niet van betekenis zijn.

Toekomstig onderzoek

Het toekomstig onderzoek zou zich moeten concentreren op het vinden van andere geschikte grassen en leguminosen om het mengsel van *Bb* + *Ap* te aan te vullen vanwege het gevaar dat er iets zou gebeuren met een van de componenten van het huidige mengsel. Er is ook behoefte aan ecologisch onderzoek om de concurrentieverhoudingen tussen *Ap* en grassen te bestuderen teneinde de vestiging van *Ap* te verbeteren en om te leren hoe de gras-leguminosen balans kan worden beïnvloed door beweiding.

Conclusies

Gedurende de 2,5 jaar beweiding vormde *Ap* een goed mengsel met *Bb* bij HSR. *Ap* heeft verscheidene eigenschappen die nodig zijn voor standvastigheid en dit zou moeten leiden tot langdurige duurzaamheid in mengsels met geschikte grassen bij de juiste beweidingsdichtheid.

Cm en *Sg* faalden in standvastigheid gedurende de 2,5 jaar van beweiding en dit werd veroorzaakt door een combinatie van gebrek aan beweidingstolerantie, een korte levensduur en het niet kunnen produceren van voldoende zaad om vervanging van planten te verzekeren.

De voederwaarde van *Bb, Bh* en *Ap* werd gekenmerkt door hoger CP en IVDMD dan dat van andere grassen en leguminosen in de Atlantische Zone van Costa Rica.

CURRICULUM VITAE

Muhammad Ibrahim was born on June 20, 1958 at Rose Hall Canje, Berbice, Guyana. He finished secondary education in 1976 and received a diploma in Agriculture from the Guyana School of Agriculture at Mon Repos, Demerara in 1980. After graduation he was employed as an Agricultural Technical Assistant in the Ministry of Agriculture but resigned in September 1981 to undertake undergraduate studies at the University of Guyana where he obtained a BSc in Agriculture with distinction in 1985. He received the Vice Chancellor and GAIBANK awards for the best graduating student in the Faculty of Agriculture. Between 1985 and 1987 he was employed as a senior dairy officer in the National Dairy Development Programme in Guyana. From 1987 till 1989 he studied for and was awarded MSc at CATIE with emphasis on animal nutrition.

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