Improving a native pasture with the legume *Arachis pintoi* in the humid tropics of México

Epigmenio Castillo Gallegos

Promotor: Prof. dr. ir. L. 't Mannetje

Hoogleraar in de Graslandkunde

Co-promotor: Prof. Dr. Andrés Aluja Schunemann

Universidad Nacional Autónoma de México

Promotiecommissie:

Prof. dr.ir. S. Tamminga	(Wageningen Universiteit)
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Dr. ir. H.M.J. Udo	(Wageningen Universiteit)

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ABSTRACT

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The objective of this study was to determine the effect of introducing the legume *Arachis pintoi* CIAT 17434 into a native pasture where native grasses dominated the botanical composition, on establishment, persistence, standing dry matter, botanical composition, soil variables, animal performance, herbage quality and ingestive behaviour of the animals, from 1998 to 2001 in the humid tropics of the east coast of México. The treatments were the native grass pasture (NG) as control and NG associated with *A. pintoi* (NG+Ap), which were grazed by dual purpose F1 (Holstein x Zebu) cows. The most successful type of establishment was vegetative planting of alternated strips of legume and grass in a 1:2 ratio in area. The legume showed a strong stoloniferous habit and accumulation of a high soil seed reserves that allowed its propagation over almost half the pasture area by the end of the study. The SDM was always higher for NG+Ap but the difference among treatments decreased with time. The higher SDM and the effective N_2 fixation allowed the accumulation of C and N in the NG+Ap soil, and in both treatments the bulk density of the soil remained unchanged with time. There were no differences in saleable milk yield (6 kg/cow/day) and calf production per cow (0.5 kg/calf/day) between treatments. Herbage digestibility and crude protein were higher in the association, but this did not reflect in higher animal performance because of low organic matter intakes. Grazing and ruminating times were lower in the association, but biting rates were higher. The farmer may use to his advantage the increase in soil fertility, since it would allow the introduction of more productive exotic grasses or the cultivation of crops without the need of costly N fertilisation.

PREFACE

The main objective of the Centre for Teaching, Research and Extension in Tropical Animal Husbandry (CEIEGT) is “To increase the production of milk and meat in the humid tropics of México” by training highly qualified human resources, by doing applied research on regional cattle and sheep problems, and by extending the results of research to farmers. A major problem has been the absence of techniques applied to pastures to improve cattle and sheep productivity. An alternative to improve cattle productivity is the use of grass-legume associations, a subject well researched in Australia and Latin American countries like Colombia and Costa Rica, but sparsely studied in México. The personnel of the Forage and Nutrition Section of the CEIEGT have been involved in tropical pasture research since its foundation in 1980. For several years the efforts to find a legume “persistent” under grazing were fruitless. As a result of a visit that Dr. Andrés Aluja, then Technical Director of the CEIEGT, made to CIAT, Colombia in 1985 the CEIEGT joined the International Network for Tropical Pastures Evaluation (RIEPT) in 1987, which made it possible to evaluate under the environmental conditions of the Centre new pasture grass and legume germplasm. The subsequent agronomic and preliminary grazing trials identified *Arachis pintoi* CIAT 17434 as a promising legume for the lowland humid tropical agro-ecosystem of Veracruz. Dr. Aluja was also responsible of bringing Professor Dr. Len ‘t Mannetje, a leader in research and education of grassland science, for the first time to the CEIEGT, in 1993. Dr. ‘t Mannetje’s visit was a fruitful one, since it resulted in a proposal to develop a research project for a PhD degree at Wageningen University, in which the benefit of introducing *Arachis pintoi* into native pastures was to be evaluated. Therefore I am in great debt to Dr. Aluja, not only because he was instrumental in facilitating my path to a higher academic degree, but more than that, because of the friendship we share, something I will forever appreciate.

Over the last forty five years Professor L. 't Mannetje has been a leader in pasture and grassland research and education world-wide. I am greatly indebted to him because without his moral and academic support, the objectives of this research could not have been attained.

The financial resources that supported this research came from the CEIEGT, that provided the land, animals and labour whenever it was necessary, the General Directory of Academic Affairs (DGAPA) of the National University, which provided most of the funds for my stay in

Wageningen, the National Council for Science and Technology, through its regional branch SIGOLFO, which awarded the seed money for the research project, and Wageningen University. My gratitude to these institutions.

I am thankful to MCV Jorge Armando Alvarez León, the current Technical Director of the CEIEGT for the full support I have received from him. Jorge, more than a boss, is a facilitator to his staff. It is an honour to be under his leadership.

My colleagues MSc Jesús Jarillo, Ing. Eliazar Ocaña and MSc Bernardo Marín are gratefully acknowledged for their support in managing pastures and animals.

Several measurements could not have been possible without the diligent work of several students who developed within this large research project, several short term projects. My gratitude goes to, in order of appearance: Chantal Vos (Wageningen, The Netherlands), Carlos Sosa (Mexico City), Ricardo Monsalve (Bogota, Colombia), Alfredo Blanco, Diana Garcia, Rodrigo Rascon, Ricardo Ramirez, Luciano Hernandez and Lidia Ascencio (Puebla, Mexico) and Karla Rodriguez (Mexico City).

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The staff and student body of the Crop and Weed Ecology Group of Wageningen University always supported me morally and technically to finish this thesis. My thanks to Lammert, Maja, Gon, Rick, Paula, Harm, Nick, Jochem and Santiago.

My wife Maria Guadalupe and my children Epigmenio III, Nadia and Livia have always supported me in my professional career and my graduate studies. My love and gratitude go to them.

My sisters Magdalena, Gabriela, Virginia, Delia and Graciela and brother Gustavo have been particularly supportive of myself during my time in The Netherlands.

I dedicate this thesis to my mother Josefina Gallegos Montes and the late Epigmenio Castillo Estrada, my father, for always encouraging me to get a higher education. You got your way.

Table of contents

1

GENERAL INTRODUCTION

1. GENERAL INTRODUCTION

1. 1 Introduction

Milk is an important food source of high quality protein for human nutrition. In México, milk has been at the centre of an extended debate on economics and politics. The national system of milk production has been unable to satisfy demand, leading to huge imports of milk and milk-derived products. Government price regulation policies for the product along with large imports of cheap powdered milk to cover the potential demand and to support government programs to aid the economically poor population, have rendered milk production uneconomical, discouraging farmers to continue with this activity.

1. 2 Demand for milk in México

Livestock production is a demand driven economic activity that responds to market influences. Demand for livestock products is determined by consumer preferences, income level, and population size. Any change in these factors will cause changes in the level of demand. Based on a recommended milk intake per person of 0.337 ml (123 litres/person/year) (García, 1996) and population numbers, the potential demand for milk and milk production for the years 1990, 1995 and 2000 are presented in Table 1. 1.

Table 1. 1. Potential demand and estimated milk production for México in 1990, 1995 and 2000.

Variable	Year		
	1990	1995	2000
Potential demand (litres x 10^6)[1]	9994	11213	11976
Production (litres x 10^6)[2]	6142	7399	9311
Percent demand covered by production	61.5	66.0	77.7

1. Population x 0.337 litres/person.
2. Source: Secretaria de Agricultura (2001).

National milk production covered 61%, 66% and 78% of the potential demand of 1990, 1995 and 2000, respectively. As a result México became the greatest net importer of dehydrated skim milk (DSM), to the extent of 30% of the total DSM sold in the world import-export market between 1994 and 1999 (Secretaria de Agricultura, 2001). Government authorities have preferred to encourage DSM imports instead on investing on programs to develop and increase the national milk industry. The main reason is that the price of a litre of milk from imported DSM is cheaper than the local cost of production. Assuming that 0.13 kg of DSM goes into a litre of milk, its cost would be a very low US$ 0.17, which is a potent lure for the milk industry that goes after DSM instead of paying a higher price for locally produced fresh milk. This has encouraged Mexican farmers to leave the industry, with the negative effect of increased unemployment among the rural population that favours migration to large cities and the USA.

1. 3 Milk production systems in México

México varies widely in climate and topographical conditions. Five ecological regions are recognised. The northern plateau, is a continuation of the central plains of the USA, the central plateau, a continuation of the latter but higher in altitude, the Gulf of México and the Pacific Ocean coastal plains, which are separated from the plateau by the east and west mountain chains, respectively, and the peninsula of Yucatán.

About two thirds of the country have dry and very dry climates, in which evaporation exceeds rainfall. These areas are not suited for arable cropping and are used mainly for very extensive beef cattle raising.

1. 4 Intensive production systems

Paradoxically, these dry areas contain the intensive milk production systems (IPS) of the country. These follow the American model, based on housed, pure-bred Holstein cows and make use of high levels of inputs, such as large amounts of concentrates, irrigation water and fertilisers to produce hay or silage. This system has 8% of the country's cattle numbers and contributes roughly with 25% of the total milk produced. Production units are relatively big, highly specialised and managed with entrepreneurial skills. There is a high degree of mechanisation. As a result, there is a high productivity of the herds and of labour. Production units sell milk to large companies, generally under contract, or to cooperatives formed by the producers themselves. Milk production per cow is more than 5500 kg/lactation and herd size is rarely below 500 head (Odermatt and Santiago, 1997).

1. 5 Family production systems

There are family operated production systems (FPS) all over México. These have evolved under varied conditions of soils and topography, but generally are located in temperate dry to humid highlands, and are located around big cities. In these, production units are small and diversified; labour comes almost exclusively from the family with some mechanisation (tractor, milking machine). The production unit can have from 2 to 20 cows, generally Creole but also with some graded Holsteins, and grazed pasture land can be 0 (cut and carry) to 40 ha. In drier regions, cattle are fed with pasture produced forage during the rainy season and with maize stover during the dry period. In all cases, cattle feeding is highly dependent on purchased concentrates. Milk yields per lactation per cow are around 2500 kg. Milk is sold to collection centres and/or at farm's gate, and almost none of it is industrialised (Odermatt and Santiago, 1997; Zorrila *et al*., 1997). Forty five percent of Mexico's milk is produced under "backyard" conditions, in very small sized operations. (Barbabosa and García, 1997; González *et al*., 1997).

1. 6 Dual production systems in México

Dual-purpose systems (DPS) are present mainly in the tropical lowlands along both coastal plains and the Yucatán peninsula (Corro *et al*., 1997). The research described later in this Thesis was situated in the humid tropics of the State of Veracruz, México, under a specialised type of DPS. For this reason, a more detailed account is given of the main features of the DPS in tropical México[1].

The DPS was initially generated from the cow-calf operations where the main objective was to produce calves for fattening and milk was considered a by-product, since only those cows considered as "superior" by the farmer were milked (García, 1996).

Two types of DPS have been defined: Traditional, where only the superior cows are milked, without any investment for improvement, and improved or specialised, where all cows are milked, both management and the animals are more specialised.

About 70 % of farms can be considered smallholdings. As the cattle numbers increase, more farms are privately owned: 40% of farms with 1 to 80 cows and 90% of farms with more than 81 cows.

About 80% of farms have an agricultural activity other than the DPS within the farm. The DPS system has a high requirement for labour. Ninety percent of farmers directly manage their farms. On average, two persons belonging to the family work in the DPS farm and hired labour varies according to the size of the farm.

A fundamental aspect to understand the DPS system is the motivation of the farmer to stay in this business: 81% of the DPS farmers state that "the most important factor is the daily income from milk". This allows the farmer to face production costs of the farm; most of the time he breaks even with milk income. A profit is reached only when weaned calves are sold. Besides, the DPS allows the farmer a great deal of flexibility to change towards better calves at weaning or higher milk yields, if the market prices favour one product over the other.

[1] This description is mostly based Menocal *et al*. (1992 a, b, c,). For this reason, these references will be cited only if necessary. Other references are quoted that give complementary information.

The DPS are extensive and cattle feeding is based on grazing of native grass or introduced/naturalised grass pastures. Eighty percent of DPS farms have African Stargrass (*Cynodon plectostachyus*; *C. nlemfuensis*) in their pastures. Second in importance, mainly in the humid tropics, are native grass pastures (44%), and in drier areas Jaraguagrass (*Hyparrhenia rufa*, 20%-30%) and Guineagrass (*Panicum maximum*, 23%-55%). In recent years Llanerograss (*Andropogon gayanus*) a species released by CIAT, which is tolerant to drought, spittlebug attacks and low fertility soils, is making inroads into the DPS of the dry tropics and *Brachiaria brizantha*, also released by CIAT, is being adopted in the humid tropics. Other grasses used by DPS farmers are Pangolagrass (*Digitaria decumbens*, 15%-28%) on fertile soils, or Paragrass (*Brachiaria mutica*, 9%-24%) and Alemangrass (*Echinochloa polystachya*, 6%-17%) on temporarily or permanently flooded soils.

Pasture dry matter production is very seasonal. Forage grows very rapidly during the rainy season (June to November) and very little during the dry, winter season (December to May). Seventy percent DPS farmers consider seasonal forage production as the main constraint to increase milk yields. However, farmers do not take measures to overcome feed shortages during the dry season, by means of conserved forages and concentrate supplements. Half the farmers never supplement their cattle; 40% supplement cattle only in the dry season. Only 4% to 5% use supplements all year round. Internal divisions of the pastures are scarce: four paddocks on the average. However, pasture division increases as cattle numbers increase. Only 10% of the DPS farmers fertilise their pastures. Of those that fertilise, 90% apply fertiliser only on some pastures or divisions. Three percent fertilise all their pastures. Weed control is the most commonly used pasture management practice by DPS farmers: 70% of them do it. Again, pasture technology can provide pasture legumes that, besides improving the diet of cattle, can also improve soil fertility through biological nitrogen fixation (BNF) (Mannetje, 2000).

In general, cows form 40% to 45% of the herd, with suckling calves comprising about 25%. The calves are necessary to keep the cow productive, by stimulating milk let-down. Weaned male calves represent only 5% to 15% of the herd, because they are sold at an early age due to severe dry seasons, and because if kept on the farm, they would compete for forage with milking cows.

Calf suckling and the low nutritional level of the herd both have a pronounced negative effect on reproductive efficiency. Calving interval varies between 19 and 25 months, leading to low apparent birth rates (50%-60%) and reduced percentages of cows in milk (50%-60%). Twenty percent of cows are replaced every year, thus, the mean productive life of a cow is less than 5 years. This, coupled with the long calving intervals and age at first calving of 32 to 36 months, gives an average of three calves, and lactations, produced by the cow during her life. Number of cows per bull sire is around 19, an acceptable number for extensive grazing conditions. Ten percent of DPS farmers, particularly those with up to 40 cows, do not own a sire, relying on leased bulls. Only 2% of all DPS farms use artificial insemination. Up to 65% of parturitions concentrate from March to June, which results in a highly seasonal milk production pattern that eventually leads to low prices during the rainy season due to the excessive supply. These facts explain why the DPS has such a low economical efficiency.

The DPS farmer uses mostly crosses between Brown Swiss and Zebu Cows. Bulls of either breed are alternated to keep the blood percentages close to 50:50. In recent years there has been a growing interest in introducing the Holstein breed instead of the Brown Swiss, particularly in areas around cities, where demand for milk is high and a better price is paid. In this situation Holstein crosses have an advantage because they produce more milk than Brown Swiss crosses (Mc Dowell *et al*., 1996). Their use reflects a tendency towards a more specialised type of DPS.

The number of lactating cows constitute only between 21% to 27% of the total number of animals of the herd. Daily milk production per lactating cow varies from 2.9 to 4.3 l/cow. Lactation length varies from 180 to 237 days. Milk production per lactation ranges from 520 to 980 l/cow. Weaning age of calves is slightly more than 8 months and weaning weights are in the 120 to 150 kg range. Considering the low stocking rates, between 0.5 to 1 cow/ha and the reduced number of lactating cows, annual milk production/ha seldom exceeds 500 l.

Inadequate milk marketing is one of the main reasons why milk production is not higher in the DPS. On average, 20% of farmers consider the low price of the milk to be a problem. In general, the supply of milk is dispersed over large areas, it is also disorganised, and the volumes supplied by a farmer are very low. Therefore, the DPS farmer is at a disadvantage when milk price has to be negotiated.

About 8% of milk produced on DPS farms is consumed by the farmer's family, 2%-3% is given to farm workers. Eleven to 30% of farmers make cheese, particularly during the rainy season, when milk price is very low. Cheese making provides an added value to milk as well as a conservation measure. Fifty to 80% of farmers sell the milk at farm's gate. Some 30% sell milk directly in the nearest town, in order to obtain a better price. A small number of farmers sell their milk to the Nestlé company. There is a National Cattlemen Confederation, in which all regional or state cattlemen unions are incorporated; in turn regional unions are formed with municipal or local cattlemen associations. In the past, this organisation was devoted more to the political control of their affiliates, in favour of the party in power, than to provide them with better ways to produce and marketing their products. It was not until very recently and mostly as a result of the continuing economical crisis of the country, that regional unions and local associations began working toward the improvement of the economic conditions of cattlemen. Now almost each local association has a farmer's store where medicines, concentrates, barbed wire, saddles and so on can be purchased at lower prices than those in specialised stores. At present, each local association has a veterinarian who can attend to sick animals or apply preventive medicine. Unfortunately, very little has been done on the marketing of milk.

Menocal *et al*. (1992 a, b, c) collected data from different experimental stations, which show the potential that an "improved" DPS has with respect to the traditional one used by the average cattleman (Table 1. 2).

Table 1. 2. Technological gap between traditional dual purpose systems (DPS) and improved DPS for the mexican tropics (Source: Menocal et al., 1992 a, b, c).

Variable	Traditional DPS	Improved DPS	Difference, %
Stocking rate, head/ha	1.47	2.57	75
Apparent birth rate, %	56	75	34
Calving interval, days	649	484	-25
Milk yield, l/milked cow/day	3.7	6.8	84
Milk yield, l/per cow in herd/day	2.1	4.4	110
Milk yield, l/cow/lactation	783	1944	148
Lactation length, days	208	268	29
Weaning age of calves, days	253	106	-58
Milk production, l/ha/year	276	5622	1937
Weight gain of bullocks, g/day	253	758	200
Weight gain, kg/ha/year	118	643	445
Slaughter weight, kg	403	450	12
Slaughter age, months	41	22	-46

The improved model of DPS is far from reaching the milk yields of the intensive (IPS) and familiar (FPS) systems. However, it is many times superior to the current DPS. Both the current and the improved DPS are the result of the conjunction of management practices and technological levels applied. It is obvious that conditions for production are different among commercial DPS and those DPS developed at Experimental Stations. However, the latter have the great virtue of showing the milk production potential of tropical DPS. Thus, improved DPS becomes a model to follow by DPS farmers that recognise the need for higher production levels. However, it would be pretentious for the traditional DPS farmer to try to reach the production levels of the improved DPS in a short time period. Instead, this should be a medium to long term objective, where the rate of adoption of technological practices must be set by the farmer, in accordance with his economical and educational possibilities to implement the practices proposed by the improved DPS.

Increases in stocking rate as well as in production per cow can lead to considerable increases in milk production per hectare in the improved DPS as compared to traditional DPS (Table 1. 2). That increase cannot be ascribed only to pasture technology, since almost always lactating cows are supplemented during milking time and this allows for some substitution effect to occur, but even discounting the effect of supplementation, the pasture is the major potential contributor to increases in milk production per animal and per hectare.

In the early 1970's, Mexican research institutions conducted pasture studies to identify high yielding grasses which, used in combination with N fertilisation, could produce large amounts of meat and milk. The pasture model developed was rather simple and consisted of a slow rotation (3 to 5 paddocks), N fertilisation around 150 kg/ha/year and, in some cases, supplementation with molasses or other by-products during winter time. It was shown that this model was capable of doubling the stocking rate and could keep a milk production of around 6 kg/cow/day and average daily gains in the order of 0.4 to 0.6 kg/heifer/day (Fernández *et al*., 1993b). Despite its high production levels, this model was not adopted by DPS farmers.

Some trials indicated the benefit that pasture legumes can have on meat and milk production. Pangolagrass (*Digitaria decumbens*) alone or associated to the legumes perennial soybean (*Neonotonia wightii*), Centro (*Centrosema pubescens*) and Leucaena (*Leucaena* *leucocephala*) were compared with respect to weight gain (3.3 heifers/ha) and cow milk production in a hot sub-humid climate, using a 3-paddock, 42-day rotational grazing. Pastures were irrigated during the dry season. The associations produced from 25% to 38% more weight gain, and from 6% to 14% more milk, than the grass. Perennial Soybean and Centro produced more than Leucaena, but both were disappearing from the pasture a year after the beginning of the trial (Garza *et al*., 1978; Portugal *et al*., 1979). At a stocking rate of 4 cows/ha, Leucaena was the most persistent and was still in use several years after the trial (Castillo, 1999). These trials show the potential level of productivity that can be attained under irrigation in the dry tropics, but the same is not within reach under current low input conditions of the Mexican DPS farms. Other experiments (Fernández *et al*., 1993a) confirmed the lack of persistence under grazing of *Neonotonia wightii* and *Macrotyloma axillare*.

Three important points were ignored when research with grass pastures was designed: 1) farmers in the tropics of México do not fertilise their pastures; 2) once pastures were fertilised, the farmer necessarily needed more animals to consume the extra forage produced and this required capital, not always available; and 3) the choice of legume and grass species. Mexican researchers were using species like Bermuda Coast Cross 1 (*Cynodon dactylon* x *C. aethiopicus*) and Pangolagrass which show a superb performance when irrigated and fertilised, but disappear rapidly from the pasture if not. At the same time these grasses inhibit the establishment and persistence of herbaceous legumes.

As Pangolagrass, Guineagrass and Coastcross 1 are very susceptible to spittlebug (*Aeneolamia* spp.) attack farmers selected Stargrass (*Cynodon plectostachyus*), not the most nutritious of grasses, but resistant to spittlebug, able to grow on marginal soils, and capable to stand some degree of overgrazing.

Since the mid 1970's, the DPS farmers found themselves facing new problems. Highly productive Guineagrass and Pangolagrass started to die back. Although no Mexican study exists on the probable cause, the author considers that the decline in nutrient content of the soils, as a result of several decades of use, is the main reason. This hypothesis is supported by the high degree of weed infestation as well as the shift of pasture species from those that require high soil fertility, like Guineagrass and Pangolagrass to Stargrass, which does not.

The permanence of native pastures, known locally as "gramas nativas" or native grasses (NG) also supports the above hypothesis. In general, these pastures show low levels of productivity, which mean nutrients are taken up at slower rates than under more productive introduced grass (IG) pastures. In addition, NG pastures contain variable amounts of native legumes, between 2.5% to 15.4%,, which contribute to soil N (Bosman *et al*., 1990), a trait not present in IG pastures, where management aims for monocultures. Thus, NG pastures tend to persist over long periods of time.

Mexican institutions, like the CEIEGT[1], where the research described in this Thesis was conducted, joined around the mid nineteen eighties the RIEPT[2] supported by the Programa de Pasturas Tropicales ("Tropical Pastures Program") of CIAT[3], and began to follow the RIEPT's philosophy of minimum pasture inputs along with its evaluation methods (Toledo, 1982).

Agronomic regional trials in CIAT's forage evaluation scheme, indicated that for the climate and soil conditions of the CEIEGT, the most promising legumes were, in order of dry matter yield: *Centrosema acutifolium* CIAT 5568, *Pueraria phaseoloides* CIAT 9900,

[1] Centro de Enseñanza, Investigación y Extensión en Ganadería Tropical ("Centre for Education, Research and Extension on Tropical Animal Husbandry"), Facultad de Medicina Veterinaria y Zootecnia ("Faculty of Veterinary Medicine and Zootechnics"), Universidad Nacional Autónoma de México ("National Autonomous University of México").

[2] Red Internacional de Evaluación de Pastos Tropicales ("International Network for the Evaluation of Tropical Pastures").

[3] Centro Internacional de Agricultura Tropical ("International Center for Tropical Agriculture").

Desmodium ovalifolium CIAT 350, and *Arachis pintoi* CIAT 17434 (Hernández *et al*., 1990; Valles *et al*., 1992). By 1994 the plots of the regional trials had been abandoned and were being grazed by sheep. Surprisingly at that time, the only legume present in the area was *A. pintoi* CIAT 17434. Reports from Costa Rica (Heurck, 1990; Ibrahim, 1994) indicated that this was a promising legume for the humid tropics because it was not only capable to persist under heavy grazing but it was also capable to improve animal productivity.

Therefore, *A. pintoi* CIAT 17434 was chosen for further studies as reported in this thesis.

2

ESTABLISHMENT OF *Arachis pintoi* IN NATIVE GRASS PASTURES IN THE HUMID TROPICS OF MÉXICO

2. ESTABLISHMENT OF *Arachis pintoi* IN NATIVE GRASS PASTURES IN THE HUMID TROPICS OF MÉXICO

2. 1 Introduction

The establishment period is the most critical in pasture development. In tropical areas it used to start with forest clearing and burning, followed by two or more cropping cycles. As soil fertility declined, the land was either abandoned (slash and burn) or converted to pastureland. Grazing by cattle and burning every so often to eliminate scrubby weeds created a savanna type vegetation of grasses and some scarce herbaceous legumes. This was the mechanism by which many tropical forests ended up as pastures. In México, such induced grasslands are called 'gramas nativas' or "native gramma".

While introduced grasses like those of the *Brachiaria* genus have become popular in latter years, the native grass pastures, here referred as NG, are still the main source of feed for cattle.

The NG consists of a mixture of grasses of the *Paspalum*, *Axonopus*, *Cynodon* and *Setaria* genera, with small contributions of herbaceous legumes from the *Desmodium*, *Centrosema*, *Rynchosia* and *Calopogonium* genera. The most important species are *Paspalum notatum*, *P. conjugatum* and *Axonopus compressus* among the grasses, and *Desmodium canum*, *D. incanum*, *D. triflorum*, *Centrosema virginianum*, *C. pubescens*, *Rynchosia minima* and *Calopogonium caerulum* among the legumes. *Paspalum virgatum* and *Sporobolus poiretii*, and *Mimosa pigra* and *M. pudica* are important grass and legume weeds, respectively.

Under traditional management, the NP presents low dry matter (DM) yields and low nutritive quality. Carrying capacity is low, between 0.5 to 1.0 cow/ha, and liveweight gains: 0.4 to 0.5 kg/steer/day. Its productivity is highly seasonal, leading to alternate periods of good and reduced animal performance in the rainy and dry seasons, respectively (Aluja and Mc Dowell, 1984).

The benefits of incorporating legumes into tropical grasslands have been documented elsewhere (Humphreys, 1991; Mannetje, 1997) and are, among others: 1) to increase the N soil status through biological nitrogen fixation, which may eventually lead to increased DM yields and protein concentration of the forage, 2) to improve the organic matter content of the pasture, thus sequestering, CO_2 and 3) to improve the digestion of fibre in the rumen, promoting animal performance and also, a reduction of the production of CO_2 and methane in the rumen, through a more efficient use of the energy of the ingested pasture (Mannetje, 2000).

Research results from the hot humid areas of México and from other parts of Latin America showed that the forage legume *Arachis pintoi* CIAT 17434 was a good prospect to associate with grasses, because it shows better persistence than other legumes and also has high nutritive value and palatability (Argel, 1994; Lascano, 1994; Hernandez *et al*., 1995; Ibrahim and Mannetje, 1998).

Pasture establishment is an investment in which resources (seeds, planting material, biocides, labour) are used to produce a capital good (pasture), that, if properly managed, will generate benefits in the medium and long term (Aluja *et al*., 1988).

During the establishment phase, the pasture is exposed to biological risks, related to climate and weather, seed quality and the presence of weeds, pests and diseases. Risk factors are reflected in the cost of establishment, including the "unproductive" period when the pasture cannot be harvested. Thus, the decision to invest in perennial pastures depends largely on the assessment of biological and economical risks of meat and milk prices (Aluja *et al*., 1988).

The inputs considered to calculate the cost of establishment of a pasture are generally the following: 1) Seed or vegetative material, 2) soil tillage, 3) fertilisation, 4) labour, 5) machinery and implement maintenance and depreciation, 6) fuel, 7) forest clearing [if applicable], 8) insecticides and fungicides, 9) herbicides, 10) slashing for weed control, and 11) pasture leasing

(Aguilar *et al*., 1983; French and Prine, 1991). Most Mexican dual-purpose farmers will not use all of these inputs, either because of high cost in relation to farm size, or because steep slopes impede their use (mechanisation). The pasture technology inherent to management of new tropical pasture species will only be applied if the implementation costs can be recovered in the short term by higher outputs under adequate grazing management (Spain and Gualdrón, 1988).

A. pintoi establishment techniques range from a complete soil tillage and planting with seed to zero tillage and planting with vegetative material (stolons) into an existing pasture (Argel, 1994). The choice of a particular technique is a compromise between what is economically feasible and what is agronomically recommendable (Whiteman, 1980). For this reason, the different alternatives to establish *A. pintoi* into an existing pasture must be evaluated in their agronomic and economic contexts. The economical analysis of pasture establishment represents the efficiency of the present technology with respect to the availability of the resources, which in turn reflects on the relative prices of inputs, labour and other factors of the production process (Aluja *et al*., 1988).

Therefore, pasture establishment methods should be focused on minimal use of inputs, a minimum risk to the farmer (Loker *et al*., 1988) and the ability to pay back inputs in a short time (Holmann, 1999).

In accordance with the ideas mentioned above, the objective was to study the agronomic and economic performance of different techniques of establishing *A. pintoi* CIAT 17434 into existing native pastures in the humid tropics of the coastal plains of the Gulf of México.

2. 2 Materials and methods

2. 2. 1 Location, climate and soil of the experimental site

Three experiments were conducted between 1991 and 1996 at the Centro de Enseñanza, Investigación y Extensión en Ganadería Tropical of the Faculty of Veterinary Medicine and Zootechnics of the National Autonomous University of México. The Centre (CEIEGT) is located in the eastern coastal plain of México about 40 km West of the Gulf of México coast line at 20° 02' N and 97° 06' W, at 112 m. a. s. l.

The climate is hot and humid, with rains all year round. Mean yearly rainfall was 1917±356 mm from 1980 to 1997. Monthly rainfall is highly variable (Figure 2. 1) but generally enough for plant growth since dry spells are only occasional.

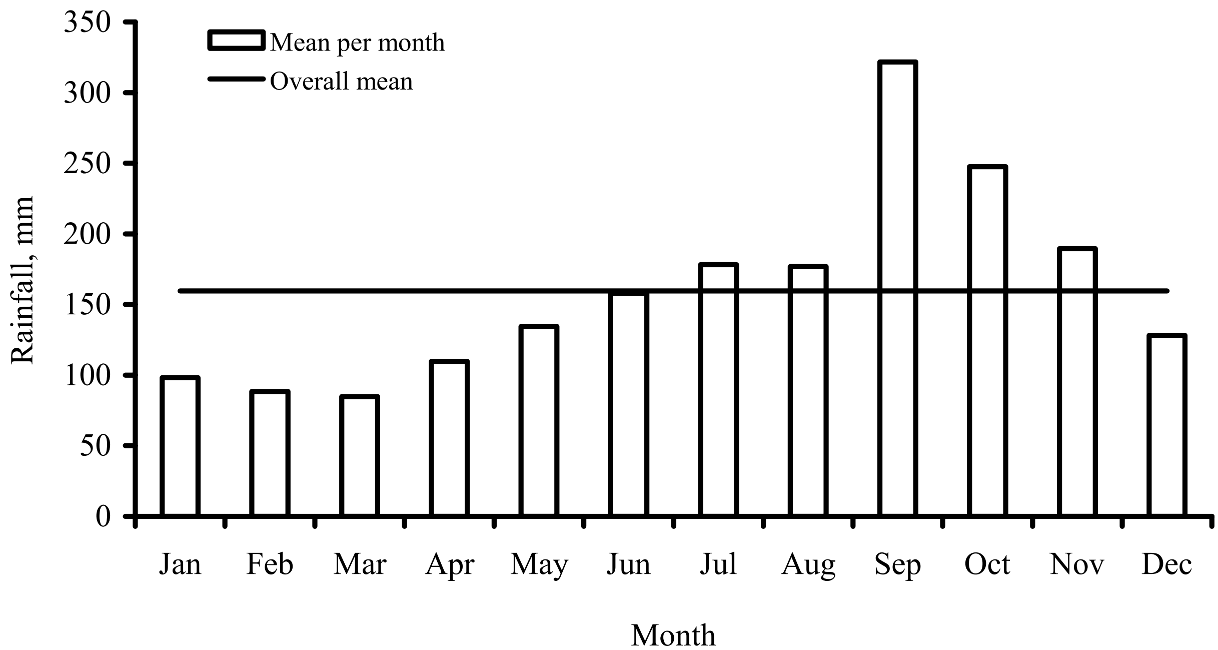

Figure 2. 1. Long term monthly rainfall for the experimental site.

Average maximum and minimum monthly temperatures are fairly uniform from year to year. The coldest and hottest months are January and June, respectively. Minimum daily temperatures from November until February (winter) are around the critical range of 8-10 °C, below which the growth of C_4 tropical grasses is severely reduced (Karbassi *et al*., 1970; Ivory and Whiteman, 1978a; Ivory and Whiteman, 1978b). From 1980 to 1997 the mean average temperature was 23.4 ± 0.5 °C. Rainfall and temperature trends throughout the year define 3 contrasting seasons: *rainy*, from July to October, with increasing rainfall and high temperature, is ideal for pasture establishment and production; *winter*, from November to February, with decreasing temperature and rainfall, is sub optimal for pasture production; and "*dry*", from March to June, with occasional dry spells which in combination with the high temperatures of these months, constitute adverse conditions for pasture production, particularly because the soils of the Centre do not store much moisture due to their shallowness (Table 2.1; Figure 2.1).

Table 2. 1. Average maximum and minimum air temperatures (°C) under cover, according to season of the year, from 1980 to 1997.

Month	Temperature[1]	
	Maximum	Minimum
Winter	28.3 ± 4.1 (14.5)	12.3 ± 2.8 (22.8)
Dry	33.8 ± 1.8 (5.3)	17.8 ± 1.6 (9.0)
Rainy	33.3 ± 2.4 (7.2)	19.4 ± 2.5 (12.9)

1: Mean ± standard deviation; coefficient of variation in parenthesis (%).

Fifty two percent of the annual rainfall occur in the 4 months of the rainy season and 48 percent is equally divided among the winter and dry seasons. These combinations of rainfall and temperature lead to a seasonal DM production pattern, a common situation in the tropics of Latin America.

The soils of the experimental site originated from weathered sandstone formed initially from old alluvial sediments. An impermeable hardpan between 0 and 25 cm in depth, results in inadequate drainage during the rainy and winter seasons. The soils are acid Ultisols (Durustults), with a range in pH from 4.1 to 5.2 and with low concentrations of P from 1.1 to 4.5 ppm (Arscott, 1978). The soil texture is clay-loam with low levels of P (< 3 ppm), S (< 30 ppm), Ca (< 3 meq/100 g) y K (< 0.2 meq/100 g). Both cation exchange capacity and aluminum saturation increase with depth, but the latter do not reach toxic levels for pasture plants (Toledo, 1986).

2. 2. 2 Experiment 1. Reduced and zero tillage, with or without fertilisation

The study was conducted in each season to test the combined effects of tillage type: reduced and zero, and fertilisation with (kg/ha): P 22; S 25; K 18, Mg 20; Ca 100; Zn 3; Cu 2 and B 1, or no fertilisation, in a 4 treatment combination: T1: reduced tillage and fertilisation; T2: reduced tillage without fertilisation; T3: zero tillage and fertilisation and T4: zero tillage without fertilisation. Reduced tillage consisted of 4 passes of a disk harrow, while zero tillage only required the elimination of pasture vegetation by machete to ground level.

The experimental area was 2000 m^2 (50 m x 40 m split in two plots of 1000 m^2 - 25 m x 40 m) where the tillage treatments were applied. These plots were divided in 2 sub plots of 500 m^2 (25 m x 20 m), of which 1 sub plot was fertilised.

A. pintoi was planted on 29 November, 1991 (winter season), 2 March, 1992 (dry season) and 2 July, 1992 (rainy season). Three to 4 stolons, approximately 15 cm in length and with 5 nodes per stolon, were planted per planting position. On the reduced tillage treatments the distance between rows and position were 1.0 m and 0.5 m, respectively. Planting was done on 3 m wide strips, that alternated with 3 m intact native pasture strips. Three rows were planted per strip and 3 strips were contained in a subplot. On the zero tillage treatment, distance between rows and positions was 2 m and 0.5 m, respectively; the subplot contained 9 sampling rows also, but since distance among rows was twice as much, the sampling plot was doubled to 6 m x 3 m, in order to have 2 positions/m^2 in each sampling quadrat regardless of type of tillage. Fertiliser was broadcast thirty days after planting.

2. 2. 3 Experiment 2. Control of native pasture growth, with or without P fertiliser

This experiment tested the combined effect of the type of pasture vegetation control: herbicide (glyphosate) or slashing (by machete) without or with burning of dead vegetation, and with or without localised P-fertilisation which resulted in 8 treatment combinations. The choice of treatments attempted to reduce competition to *A. pintoi* from existing native pasture vegetation and at the same time to enhance legume establishment and early growth, following the approach described by Cook and Ratcliff (1985) for the successful establishment of the legume Siratro (*Macroptilium atropurpureum*) and the grass Green Panic (*Panicum maximum* var. *trichoglume*) into existing Speargrass (*Heteropogon contortus*) native pastures, in Australia.

Slashing was done by machete and burning was carried out between 1-5 days after slashing. A 2% aqueous solution of glyphosate (480 g of isopropyl amine salt of glyphosate/l) was applied on a 0.25 m wide strip 15 days before planting; burning was done 15 days after herbicide application.

The legume was planted between 3 to 5 days after slashing or slashing and burning, and 15 to 16 days after herbicide or herbicide and burning were applied. Planting took place between 28 June and 3 July, 1993. Vegetative material, 0.25 m length stolons with 8 nodes, was used for planting. This material was inoculated just prior to planting with a specific *Bradyrhizobium* culture obtained by suspension of 1 kg of profusely nodulated *A. pintoi* ground roots in a solution of 7.5 l water and 1.5 l of sugarcane molasses. Three stolons per planting position were put in a hole and covered with soil, allowing about 1/3 of the stolon to remain above ground. Distances among rows and positions was 1.0 m and 0.5 m, respectively. The sub plot (9.0 m x 6.5 m) had

10 rows with 14 positions/row. Two sampling quadrats (2 m x 1 m) each with 4 positions, were randomly allocated per sub plot. Single super phosphate (30 kg of P/ha) was applied at planting in a 0.07 m depth hole adjacent to the planting position.

2. 2. 4 Experiment 3. Establisment of 3 *Arachis pintoi* accessions using seed pods

This experiment compared the establishment of three *A. pintoi* accessions using seed pods. CIAT's accessions 17434 (cv. Amarillo), 18744 and 18748, were provided from Costa Rica by Dr. Pedro Argel, from the Section for Central America, Caribbean and México of the Tropical Pastures Program of the Centro Internacional de Agricultura Tropical (International Centre for Tropical Agriculture).

Seed germination was assessed in the laboratory at room temperature using 125 seeds per accession. Petri dishes, bottom-lined with filter paper, were used and were watered twice daily. The seeding rate was equivalent to 10 kg of live seed pods per hectare. The experimental plots (10 m x 5 m; ten 5 m length rows/plot) were established within a grazing experiment where milk production form native pastures and native pastures associated with *A. pintoi* was to be compared. Three replicates were established in one paddock and 3 in another. Each replicate had 3 plots, with an accession each. Plots were excluded from grazing for the 12 weeks of the establishment period. A 2% aqueous solution of glyphosate was applied on a 0.30 m wide strip 15 days before planting to eliminate competition from existing vegetation. Distance between rows and planting positions was 1.0 m and 0.5 m, respectively. Seed pods were deposited in a 5 cm deep hole made with pointed wooden stick, and lightly covered with soil by the planter’s foot. Three replicates were planted on 2 August and 3 on 3 September, 1996. Fertiliser was not applied.

2. 2. 5 Measurements and statistical analyses

The response variables were: 1) plant number (PN, plants/m^2) by counting; 2) plant height (PH, cm), on each plant within the sampling quadrat, measured with a ruler from the soil surface to the uppermost part of the plant; and 3) soil covered by the legume or cover (COV, % of quadrat area covered by the legume) measured with the aid of a 1 m^2 quadrat, divided into 25 squares, which was placed over the row. These measurements were done on weeks 4, 8 and 12 after planting (Toledo and Schultze-Kraft, 1982). In experiment 1 PH was not measured, but COV was measured again at 24 weeks after planting.

In experiment 1 there were no field replications, since it was perceived that treatments applied in larger areas would have a closer resemblance to that of farmers' fields. Also, if several sampling quadrats were used within each treatment plot, this would yield information as useful as that obtained from traditional randomised complete block designs. In experiments 2 and 3 the design was a randomised complete block design with 3 blocks as replicates. The treatment design was a split-plot in experiment 2, where the main plot was the combination of type of pasture vegetation control (slashing and herbicide) by burning (without and with) and P application (without and with) was the sub-plot; additionally the effect of week after planting was considered a sub-sub-plot. The treatment design of the third experiment was a split plot, in which the main factor was the combination of month of planting by accession and weeks after planting the sub-plot. Analyses of variance were done with linear additive models in accordance to the experimental design (Steel and Torrie, 1980). The natural log transformation of the response variable was used if its response to time was exponential. If necessary, linear or exponential relationships provided rates of increase with time in the measured variables.

2. 2. 6 Cost of establishment

Prices of inputs for July 31, 2001 were used to estimate establishment cost. The current exchange rate of US$ 0.109/Mexican peso was used to convert prices to US dollars. The prices quoted below were used for cost calculation in the 3 experiments.

Current wages for temporary field work paid by the National Autonomous University of Mexico (US$ 7.63 per man-day) and long term labour figures for the Centre resulted in a cost/ha of slashing of US$ 152.60 and of *A. pintoi* planting of US$ 305.20/ha.

The cost of vegetative material was the selling price to farmers of US$ 0.60 per kilo of stolons. Field records (n = 100) indicated that about 250 kg of vegetative material are necessary to introduce *A. pintoi* into a hectare of native grasses. The availability of seed pods of *A. pintoi* is occasional on the Mexican seed market, so the mean price from 1995 to 1998 of US$ 19.08/kg was used.

Average soil tillage cost/ha, calculated from 4 sources, was US$ 45.56 for 1 pass of plough, US$ 28.01 for 2 passes of disc harrow, and US$ 28.01 for furrowing.

Glyphosate herbicides price/litre depends on the amount purchased. For this reason, an average price of US$ 6.60/l was used on all cost calculations.

The average price per kilo of single superphosphate (8.6 % P, 20.4% Ca, 11.9% S) was US$ 0.09, of K-Mag (18.5% K, 11.2% Mg and 22.7% S) was US$ 0.23, of limestone (71% Ca) was US$ 0.20, and of Zinc Sulphate (40% Zn and 20% S), of Copper Sulphate (40% Cu and 20% S) and of Sodium Borate (11% B) was US$ 1.45.

It was considered that the establishment phase was completed 12 weeks after planting. An estimated value of non-generated income during establishment of US$ 9.81/cow/month (regional cost of pasture leasing) was added to cost of establishment.

A cost structure table was built for each establishment treatment. Cost of establishment was divided by legume cover (COV, %) 12 weeks after planting, to obtain the cost of a unit of COV 12 weeks after planting.

2. 3 Results

2. 3. 1 Climate

The experiments were conducted in different years, so climate was variable among experiments. Total rainfall during experiment 1, December 1991 to September 1992, was 39% above average (Figure 2.2b). Rainfall in the experimental planting seasons was 339 mm in winter (November 29, 1991 to February 14, 1992), 637 mm in the dry season (March 2 to May 18 of 1992) and 1352 mm in the rainy season (July 2 to September 17 of 1992). Temperatures were typical of each season, but the current maxima were below, and the current minima above the long term (1980-1997) means (Figure 2.2a). Rainfall was 19% above average during experiment 2 in 1993, but rains in 1996 were 43% below average for experiment 3 (Figure 2.2b).

2. 3. 2 Experiment 1. Reduced and zero tillage, with or without fertilisation

The main effect of treatment on plant number (PN) was highly significant ($P<0.01$) in all seasons. The linear effect of week after planting was highly significant ($P<0.01$) on PN in the winter season of 1991-92 and the rainy season of 1992, but it was not significant ($P>0.05$) in the dry season of 1992. There was no significant treatment x week interaction on PN in any season. The main effects of treatment and week after planting and its interaction were highly significant ($P<0.01$) on COV, except for the interaction in the rainy season. Weeks to reach 50% cover were 21 for T2 in the winter, 21 for T4 in the dry season and 20 for T1 and T4 in the rainy season (Table 2.2).

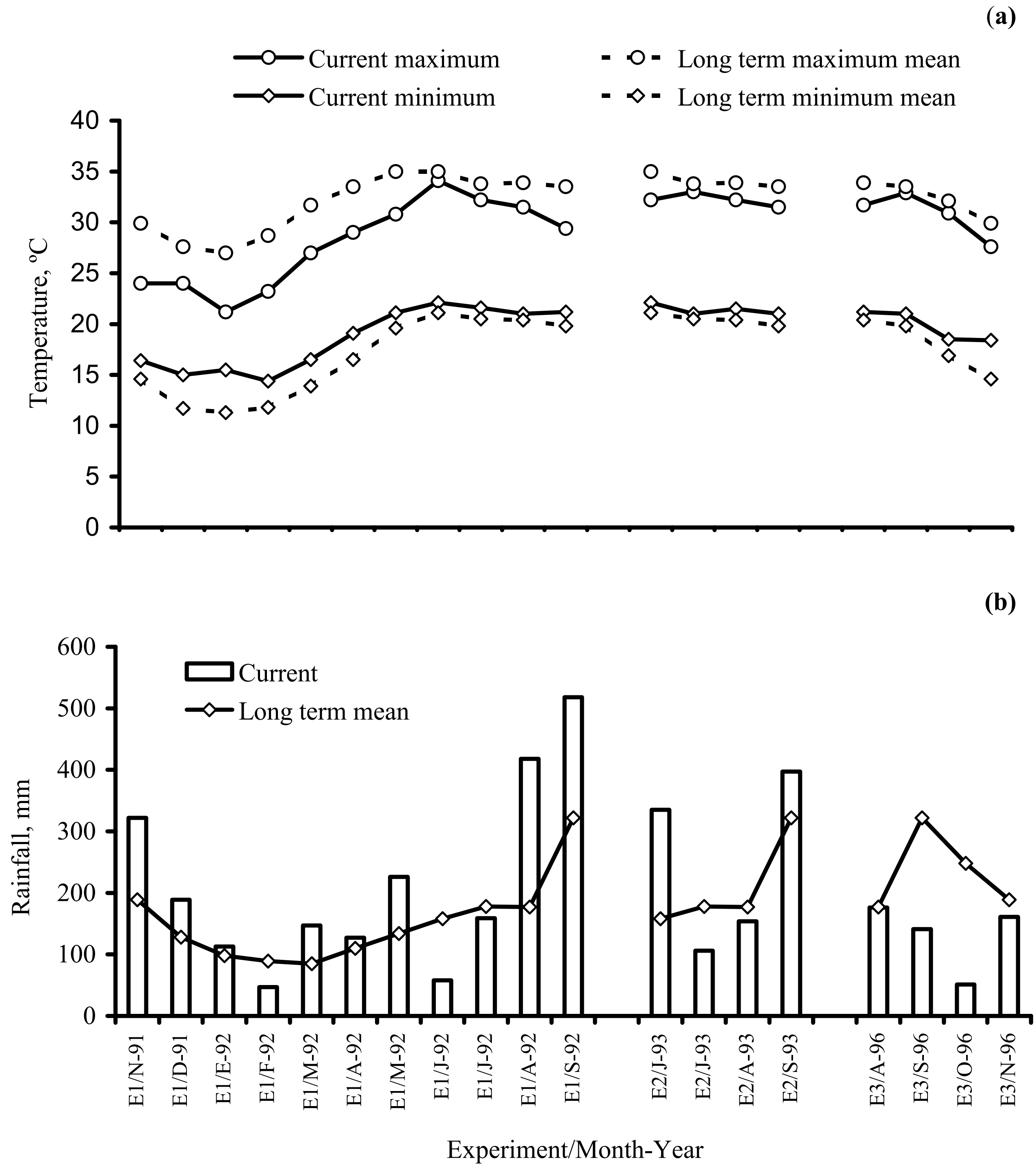

Figure 2.2. Current and long term monthly temperatures (a) and rainfall (b) for the 3 experiments.

Table 2. 2. Mean ± standard error for weeks to reach 50% cover by *A. pintoi* CIAT 17434 according to the tillage by fertilisation combination in experiment 1.

Treatments			Season		
	Tillage	Fertilisation	Winter	Dry	Rainy
T1:	Reduced	With	22 ± 0.4	25 ± 0.8	20 ± 0.3
T2:	Reduced	Without	21 ± 0.3	24 ± 0.7	21 ± 0.5
T3:	Zero	With	23 ± 0.4	23 ± 0.5	21 ± 0.4
T4:	Zero	Without	24 ± 0.3	21 ± 0.6	20 ± 0.2

2. 3. 3 Experiment 2. Control of native pasture growth, with or without P fertiliser

The main effect of week after planting was highly significant ($P<0.01$) on all response variables, which values increased with time, but to a different degree. PH increase with time was much larger than the increments of the other two response variables. The standard deviations were high in all cases and increased with time also. The coefficients of variation remained relatively uniform through time: 28% to 31% for PN, 29% to 35% for PH, and 75% to 83% for cover (Figure 2.3).

When herbicide was applied, the burned plots produced taller plants than the non-burned ones ($P= 0.01$), but the contrary happened on slashed plots ($P<0.05$) (Table 2.3).

P fertilisation did not increase ($P>0.05$) legume cover in any vegetation control by burning combination. Slashing without burning and without fertiliser, the treatment requiring the least external inputs, had significantly ($P<0.05$) less legume cover than the herbicide plus burning plus fertilisation treatment, the treatment requiring the most external inputs (Table 2.4).

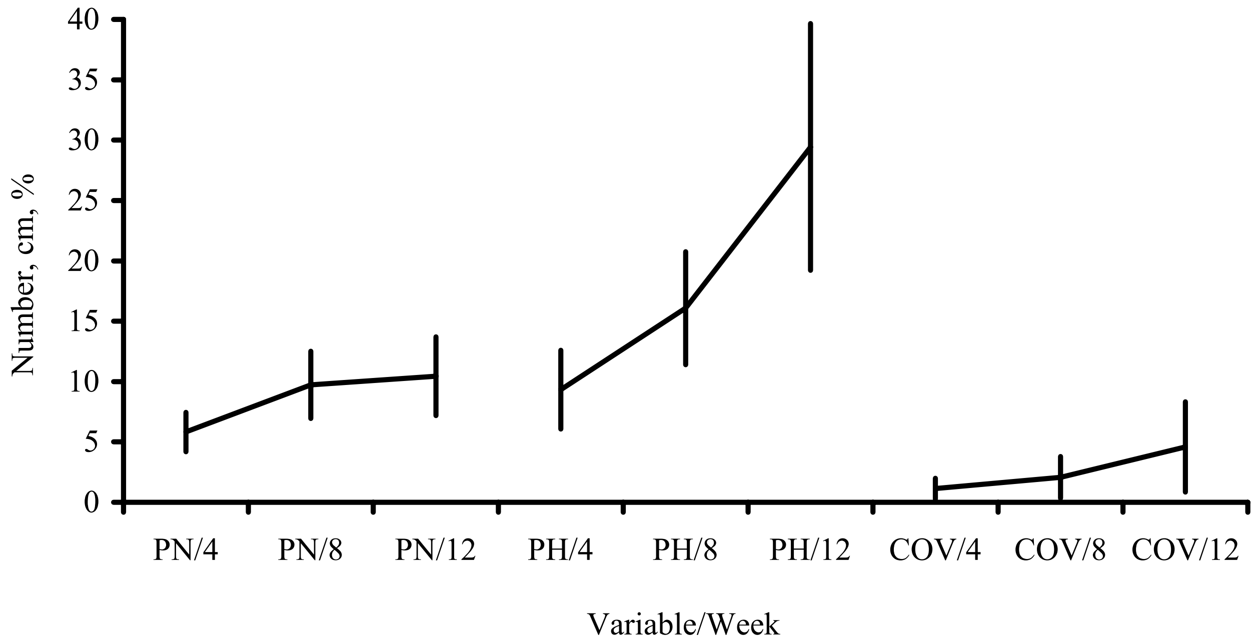

Figure 2. 3. Effect of week after planting (4, 8 and 12) on *A. pintoi* CIAT 17434 plant number (PN, number/m^2), plant height (PH, cm) and legume cover (COV, %) in experiment 2. The vertical lines are the standard deviations.

Table 2. 3. Combined effect of vegetation control by burning on mean plant height (PH, cm) in experiment 2.

Treatments		Plant height (cm)	Non-Burning vs Burning within vegetation control comparison significance
Vegetation control	Burning		
Herbicide	Without	14.54 ± 1.14	0.01
Herbicide	With	21.01 ± 1.57	
Slashing	Without	20.89 ± 1.23	0.05
Slashing	With	17.09 ± 1.25	

2. 3. 4 Experiment 3. Establishment of 3 *A. pintoi* accessions using seed pods

The main effects of month of planting and accession were significant (P<0.05) on COV. Legume cover increased linearly with time, but without differences in slope among accessions. Based on the slopes, in the August planting it took 45, 46 and 56 days to cover 5% of the soil to accessions CIAT 17434, CIAT 18744 and CIAT 18748, respectively. Values for September were 55, 50 and 55 days. Plant height was affected by month of planting (P<0.01), the plants being taller in August. The interaction month x accession was significant (P<0.05), but the accession CIAT 17434 was about 2 cm shorter than the others in both planting months (Table 2.5). Maximum height at the end of the establishment period was greater for August (27.4 cm) than for September (18.2 cm).

Table 2. 4. Combined effect of pasture vegetation control by burning by fertiliser on *A. pintoi* CIAT 17434 mean cover (COV, %) in experiment 2.

Treatment combination			Cover, %
Vegetation control	Burning	Fertilisation	
Herbicide	Without	Without	2.39 ± 0.45
		With	2.18 ± 0.54
	With	Without	2.48 ± 0.42
		With	4.21 ± 0.91
Slashing	Without	Without	1.74 ± 0.31
		With	2.59 ± 0.84
	With	Without	3.17 ± 0.69
		With	2.01 ± 0.52

Table 2. 5. Mean ± standard error of cover (COV, %), plant number (PN, plants/50 m^2) and plant height (PH, cm) per month of planting by accession combinations in experiment 3.

Month	CIAT accession	Cover, %	Plant Number	Plant height, cm
August	17434	6.4 ± 0.8	109 ± 5	11.9 ± 1.4
	18744	6.2 ± 0.8	106 ± 6	13.8 ± 1.6
	18748	5.1 ± 0.7	97 ± 6	14.3 ± 1.6
September	17434	5.1 ± 0.7	124 ± 2	9.6 ± 0.9
	18744	5.8 ± 0.7	113 ± 3	12.1 ± 1.0
	18748	5.2 ± 0.6	99 ± 4	10.0 ± 0.9

2. 3. 5 Cost of establishment

The 3 experiments tested different methods for the establishment of *A. pintoi* in native grass pastures. Thus differences in the degree of use of each input produced distinct cost structures and costs. The establishment cost/ha is shown in Table 2.6 for each experiment.

In experiment 1, reduced tillage reduced the cost (T1 and T2). Tillage and fertilisation would have given a higher cost had the legume not been planted in strips, in which case, only half the area was sown. On the other hand, slashing resulted in higher cost due to the high number of man-days to slash vegetation and to plant the legume, and also because the whole area was planted (T3 and T4).

In experiment 2, the cheapest establishment (US$ 328.21) was obtained by only applying herbicide without burning and without fertilising (H –B –F). On the other hand, slashing, burning and fertilisation (S +B +F) was the more expensive treatment (US$ 536.58). The herbicide reduced establishment cost by US$ 101.25/ha, compared to slashing, because hand labour was used for slashing (28.44% to 35.53% of total cost). Burning only increased cost by US$ 3.88/ha, while fertilising increased cost by US$ 103.30/ha.

Table 2. 6. Cost (US$)of a cover-unit 12 weeks after planting in the 3 experiments where *A. pintoi* was introduced within established native grass pastures.

Experiment One[1, 4]			
Treatment	Cover	Cost	Unit cost
W-T1	11.2	374.75	33.46
W-T2	15.0	318.34	21.22
W-T3	11.2	622.71	**55.60**
W-T4	11.3	521.02	46.11
D-T1	9.1	374.75	41.18
D-T2	9.1	318.34	34.98
D-T3	16.9	622.71	36.85
D-T4	22.1	521.02	23.58
R-T1	26.9	374.75	13.93
R-T2	23.8	318.34	**13.37**
R-T3	16.9	622.71	36.85
R-T4	15.6	521.02	33.40

Experiment Two[2, 4]			
Treatment	Cover	Cost	Unit cost
H +B +F	7.2	435.33	**60.46**
H +B –F	3.8	332.03	87.38
H –B +F	3.8	431.51	113.55
H –B –F	3.9	328.21	84.16
S +B +F	3.3	536.58	162.60
S +B –F	5.6	433.28	77.37
S –B +F	4.2	532.76	126.85
S –B -F	2.2	429.46	**195.21**

Experiment Three[3, 4]		
Treatment	Cover	Unit cost
Aug-17434	9.3	**30.33**
Aug-18744	9.1	30.99
Aug-18748	7.5	**37.60**
Sep-17434	7.6	37.11
Sep-18744	8.4	33.58
Sep-18748	7.6	37.11

1. W, D and R stand for winter, dry and rainy seasons, respectively. Treatments are: T1, reduced tillage with fertilisation; T2, reduced tillage without fertilisation; T3, zero tillage with fertilisation; and T4, zero tillage without fertilisation.
2. H is glyphosate application, S is slashing of pasture, B is burning of dead vegetation left by herbicide or slashing, F is fertilisation. The preceding + or – sign indicates that burning and fertilisation was applied or not applied, respectively.
3. Numbers after the month are those of *A. pintoi* CIAT accessions. The establishment cost was the same for all treatments: US$ 282.03
4. In bold the lowest and highest cost per unit of cover, within each experiment.

Experiment 3 produced the cheapest establishment: US$ 282.03, which was 89% and 86% of the cheapest treatments on experiments 1 (T2) and 2 (H –B –F), respectively.

The lowest cost of a cover unit 12 weeks after planting was for T2 in experiment 1 (US$ 13.37), for H + B +F in experiment 2 (US$ 60.46) and *A. pintoi* CIAT 17434 planted in August (US$ 30.33) (Table 2.6).

2. 4 Discussion

A species may be adapted itself to a given environment, but this is no guarantee that it will establish well. Thus, the agronomist and the farmer must do everything economically possible to ensure successful establishment in the shortest time (Chambliss, 2001).

In experiment 1, reduced tillage gave better results than zero tillage during the winter season, but the opposite occurred in the dry season. As soil moisture and temperature conditions improved in the rainy season, the difference between reduced an zero tillage disappeared. Other trials conducted in the same region have indicated the advantage of reduced tillage over zero tillage to establish vegetatively planted *A. pintoi* (Díaz-Lima and Valles, 1997; Núñez, 1997). The literature shows a general agreement among researchers in that some sort of soil disturbance is necessary to assure establishment (Chambliss *et al*., 2000; Schulke, 2000).

Cook and Ratcliffe (1984) suggested that seedlings facing more root competition from existing vegetation responded to fertilisation, whereas those without competition had a lesser or nil response.

In the winter season planting of experiment 1, fertilisation failed to stimulate COV of slashed plots, those supposedly with a larger competition from existing pasture. In the dry season planting, fertilisation was detrimental to COV in the slashed plots, in contrast to what was found by Cook and Ratcliffe (1984); finally, in the rainy season the effect of fertilisation was nil. The second experiment showed a positive effect of fertilisation on COV only when herbicide was applied and the dried vegetation was burned. When plots were slashed, but not burned, the effect of fertilisation on COV was positive. Nevertheless, when the slashed plots were burned, the fertilisation effect on COV was negative.

Fertilisation with 23 kg P/ha, 25 kg K/ha, 20 kg S/ha and 20 kg Mg/ha had a positive effect on COV (83.4% *vs.* 61.3%) and PH (12.0 cm vs. 8.6 cm) when the soil was prepared with 4 passes of disc harrow, but with zero tillage, fertilisation reduced both COV (25.0% vs. 30.6%) and PH (8.4 cm vs. 10.1 cm) (Núñez, 1997).

As suggested by the inconsistent results of our trials and those of the literature, fertilisation appears not to be of great importance for the establishment of *A. pintoi*, when vegetative material is used.

The main benefits of burning are vegetation removal and improved seed-soil contact. However, competition from existing vegetation is removed only for a short time after planting. Furthermore, burning can soften seed from volunteer species, that can lead to weed encroachment (Blackett and Clem, 1997). Burning can also be applied after herbicide suppression of the existing vegetation, in which case the removal of competition for the planted species is longer.

In experiment 2, burning was directed to reduce competition from existing grasses, since the way *A. pintoi* vegetative material was planted, assured a close contact with the soil. However, burning, as well as fertilisation, did not show a clear positive trend either on COV or on PH.

When only herbicide was applied in bands in experiment 2, pasture canopy height was not reduced, leading to reduced PH of *A. pintoi*. On the other hand, when the herbicide treated vegetation was burned, PH of *A. pintoi* was not impeded. Non-burned plots gave slightly taller *A. pintoi* plants than those burned. The *A. pintoi* CIAT 18744 accession flowers less and produces a denser stolon mat than the other two accessions and it also has a vigorous initial growth, covering the soil more rapidly than the CIAT 17434 accession (Villarreal and Vargas, 1996; Argel and Villarreal, 1998). For this reason, a better behaviour during establishment, particularly with respect to COV and PN was expected from this cultivar. Nevertheless, in experiment 3, COV performance at the end of establishment was similar to that of CIAT 17434 (8.5% *vs.* 8.7%) and only slightly better than CIAT 18748 (7.5%). Then, the 3 accessions behaved similarly during establishment. A low initial plant emergence lead to reduced rates of cover and plant appearance rates, particularly in the accession CIAT 18748. Zero tillage failed to stimulate a rapid establishment of *A. pintoi* in these trials, the reproductive mechanisms of this species ensure that eventually it will establish and encroach within the pasture. Our experience with this legume is that eventually it ends up to be the dominant species when associated with native pasture, Stargrass, or to both. A good strategy would be to establish *A. pintoi* in strips with reduced tillage at high density. This will result in a mixed sward in a minimum of time at moderate cost.

2. 5 Conclusions

1. Neither fertilisation nor burning were successful in enhancing *A. pintoi* establishment.
2. Due to the high cost of labour, slashing resulted in costlier establishment, and it did not improve establishment either.
3. Herbicides were cost effective and also improved establishment over slashing.
4. As a result of the high amount and cost of labour for vegetative planting, introducing *A. pintoi* into native pastures using seed pods was a cheaper.
5. The 3 *A. pintoi* accessions behaved similarly during establishment.
6. The best alternative to introduce *A. pintoi* into a native pasture is by reduced soil tillage in strips using high planting densities within the strips (8 kg of pure live seed pods/ha; or 0.70 m between rows and 0.35 m between planting positions for vegetative material).

3

PERSISTENCE OF *Arachis pintoi* IN ASSOCIATION WITH A NATIVE PASTURE IN THE HUMID TROPICS OF MÉXICO

3. PERSISTENCE OF *Arachis pintoi* IN ASSOCIATION WITH A NATIVE PASTURE IN THE HUMID TROPICS OF MÉXICO

3. 1 Introduction

Legumes are essential ingredients for tropical pasture improvement because they fix nitrogen (N) and add considerably to feeding value. In the humid tropics of Costa Rica Ibrahim (1994) calculated annual additions to the soil of 128 kg N/ha on a mixture of *B. brizantha and Arachis pintoi.*

The highest liveweight gain of 937 kg/ha/year on a grass-legume pasture was recorded on a mixture of *B. brizantha* and *A. pintoi* in Costa Rica on fertile soil grazed at 6 animals/ha (Hernandez *et al*., 1995). The expected benefits from tropical grass/legume mixtures can only be achieved with persistent legumes in association with tropical grasses under grazing. *A. pintoi* has acquired the reputation of a promising tropical herbaceous legume because it has shown above average persistence. The persistence of a pasture species depends on: 1) the longevity of originally established plants, 2) the replacement of dead plants by newly established ones through the pathway: flowering – seed formation – accretion to soil seed reserves – seedling regeneration – seedling survival to flowering, or 3) plant replacement from perennating vegetative buds (Mannetje, 2000).

Persistence of plants can only be studied using population measurements, which are expensive, because they need to be conducted over long periods of time and require much hand labour (Hay *et al*., 2000).

All previous studies on the persistence of *A. pintoi* have been carried out with a sown grass species as companion sown at the same time. This chapter reports a study on persistence of *A. pintoi* introduced into existing native pasture in a hot humid site of the central State of Veracruz, México, in order to determine if the species was able to show the same persistence under these conditions. This is of importance because pasture improvement using existing native pastures without cultivation is much cheaper than full cultivation for a grass-legume mixture and it offers completely different competitive conditions.

3. 2 Materials and methods

In Chapter 2 the geographic location, climate and soil type of the study site were described. The experiment had two treatments: a native grass pasture (NG) and NG associated with *A. pintoi* CIAT 17434 (NG+Ap). The first field of the association was established between August and November 1996. Glyphosate was applied in narrow (25 cm) bands, 1.0 m apart, to kill standing grass vegetation. Three to seven days after that, stolons were planted within the bands at distances of 0.5 m between planting points. This field was lightly and intermittently grazed from May to August, 1997. From then on grazing was continued uninterruptedly. The second field of the association was established in November, 1999. In this case, the area (2.5 ha) was heavily grazed by 60 adult F1 (Holstein x Zebu) cows for seven days. Then, stolons were directly planted into the soil without the use of a weed killer in rows 1.0 m apart and at 0.5 m distances between planting positions within the rows.

There were seven divisions per pasture treatment, which were divided into three subdivisions each, so a total of 21 paddocks were available for rotational grazing, with 1 day grazing and 20 days recovery. Stocking rate was 2 cows/ha during the period of low pasture productivity: from November 1997 to July in 1998, October 1998 to August in 1999 and from December 1999 to June 2000. The remaining months the stocking rate was 3.2 cows/ha. The reduction of stocking rate took place if by the end of the year or beginning of the next, the standing dry matter (DM) yield fell below 2.500 kg/ha in any particular paddock.

3. 2. 1 Measurements

3. 2. 1. 1 Flowering

Flowers/m^2 were counted every month from March 1998 in fifty 0.25 x 0.25 m quadrats chosen systematically by walking zigzag within each division only on field 1. Flowering was nil or extremely low from December to February and for this reason the data for these months were not included in the analysis.

3. 2. 1. 2 Plant regeneration

All stolons (m/m^2) contained within a 0.25 m x 0.25 m quadrat were cut and their length measured with a ruler. The number of nodes with roots (nodes/m^2) were also counted in fifty quadrats. These measurements were done every other month from March 1998 on field 1.

3. 2. 1. 3 Soil seed reserves

These measurements were taken every six months from March 1998 on field 1. Cores of 7 cm diameter were taken from the pasture to a depth of 20 cm. There were 45 soil core samples per sampling in 1998 and 1999 and 50 in 2000. The seed was recovered from the soil by washing with abundant running water and sieving. Seeds were blotted dry and then air dried for several days before weighing. Three variables were derived, namely seed weight (kg/ha), seed numbers (seeds/ha) and unit seed weight (g/100 seeds).

3. 2. 1. 4 Plant survival

In January 1999, about 2 months after planting, 127 plants were marked with a wooden peg. Plants were inspected for survival and counted every three months from March 1999 to December 2000. In field 1 seedlings were marked with plastic covered wire rings placed around the base of the seedling stem; the number of seedlings tagged varied between 120 and 126, in July 1998 and 1999, and June 2000. Counting was done every six weeks in 1998 and 1999 and every two to three weeks in 2000. Survival rates were expressed as percentage of the initially marked plants.

3. 2. 2 Statistical analysis

The variances of flowering (flowers/m^2), stolon length (m/m^2), rooted nodes (nodes/m^2), seed weight (kg/ha), seed number (number/ha) and unit seed weight (g/100 seeds) were analysed with a model that included the effects of month (March to November) and year (1998, 1999 and 2000) of sampling and their interaction. Survival rates were not statistically analysed because they were not replicated in time or space.

3. 3 Results

Flowering, stolon length, rooted nodes and soil seed reserves increased from year to year (Tables 3.1 and 3.2). The weight of seeds varied little between years.

Table 3. 1. Period x year flowering means (flowers/m^2) of *A. pintoi* CIAT 17434 grown in association with native grasses, compared with orthogonal contrasts.

Period	Year			Contrast Significance	
	1998	1999	2000	1998 vs. 1999	1999 vs. 2000
March & April & May	32.0 ± 1.7	63.9 ± 2.9	253.3 ± 11.5	0.0429	0.0001
June & July & August	36.6 ± 3.2	110.9 ± 7.3	573.4 ± 31.3	0.0001	0.0001
Sept. & Oct. & Nov.	54.2 ± 3.5	119.0 ± 7.7	212.1 ± 18.9	0.0001	0.0001
Means	41.0 ± 1.7	97.9 ± 3.8	346.3 ± 14.8	0.0001	0.0001

A. pintoi showed a gradual increase in flowering throughout the year in the first two years, but in the third flowering peaked from June to August, and then decreased in the remaining part of the year (Table 3.2).

Table 3. 2. Means ± standard errors of stolon and soil seed reserves variables of *A. pintoi* CIAT 17434 grown in association with native grasses.

Response variable	Year		
	1998	1999	2000
Stolons			
Length (m/m^2)	9.6 ± 0.4	18.8 ±0.6	48.3 ± 1.7
Rooted nodes ($nodes/m^2$)	205.0 ± 11.4	397.2 ± 20.3	515.5 ± 23.2
Soil seed reserves			
Number/ha (x 10^6)	0.954 ± 0.156	1.599 ± 0.305	8.590 ± 0.606
kg/ha	123.0 ± 22.2	207.3 ± 38.0	764.6 ± 60.7
g/100 seeds	12.8 ± 1.0	13.6 ± 1.0	9.3 ± 0.4

Survival of adult plants was very high, since 93% of the plants tagged in 1999 were still alive 33 months later. On the contrary, seedling survival was very poor. In all years survival decreased rapidly to zero (Figure 3.1) as seedlings disappeared through death by fungi attack, harvested by ants or removed by birds.

3. 4 Discussion

A. pintoi spreads slowly with time (Argel, 1994; Bowman *et al*., 1998; Peters *et al*., 2000). Therefore, time effects on plant population variables were more or less as expected; the legume was steadily, but slowly increasing within the pasture. Therefore, flowering, and thus seed reserves, depended on the rate at which stolons grew in length, as were the number of rooted nodes.

A. pintoi CIAT 17434 starts to flower very early after planting and flower density is generally high. In Caquetá, Colombia, in a zone with mean rainfall of 3600 mm/year, average

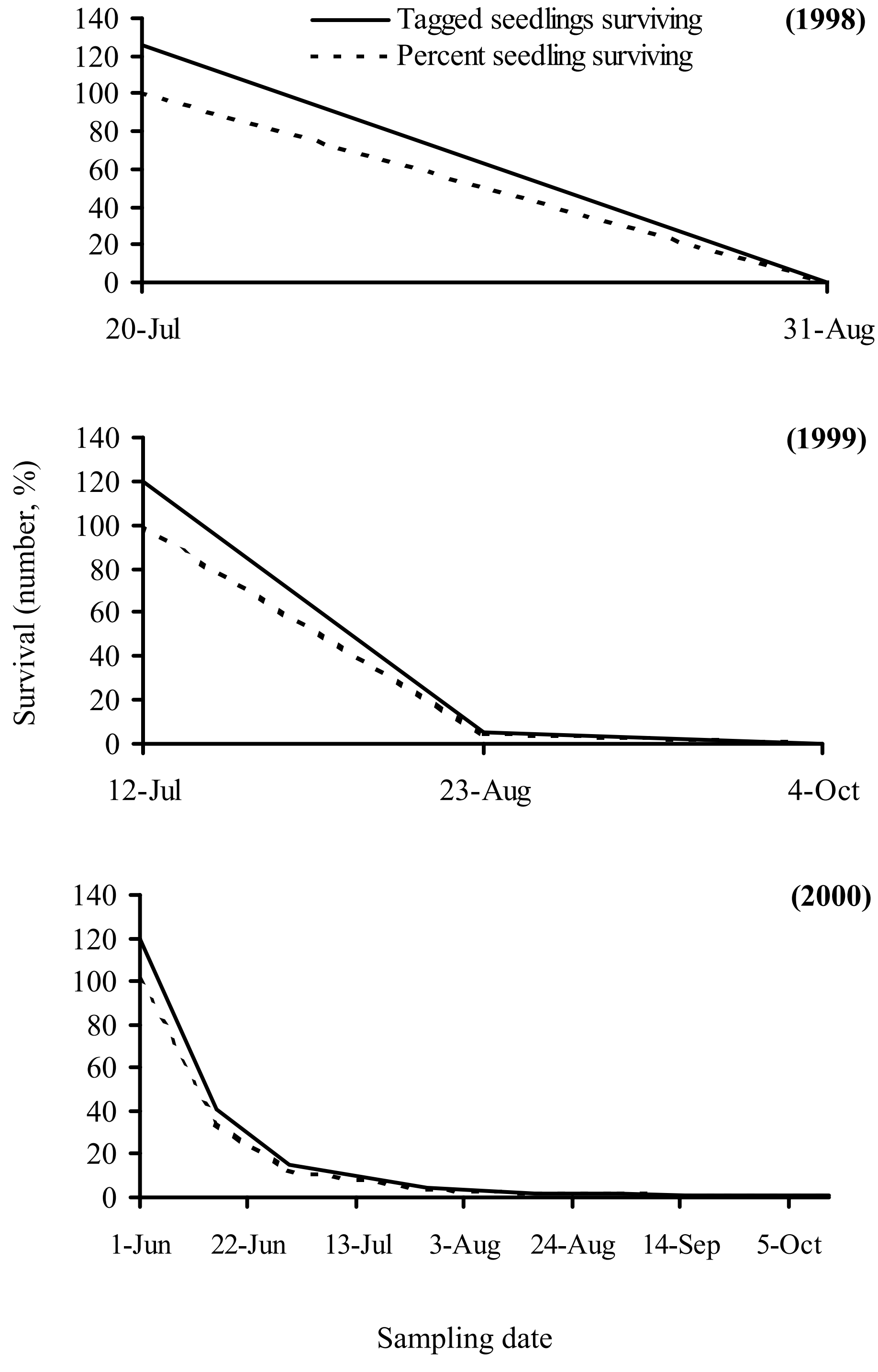

Figure 3. 1. Seedling survival (%) of *A. pinto*i CIAT 17434 of single cohorts tagged at the beginning of the rainy season from 1998 to 2000 in field 1.

temperature of 25 °C and with *B. humidicola* cv. Llanero (CIAT 6133) as companion grass, days to first flowering varied from 28 to 53 (Peters *et al*., 2000). Flower abundance six months after planting in site ranged between 239 and 265 flowers/m^2. In the present study this level of flower density was not recorded until 1999, about 31 months after planting, because of the slow stolon generation in the first years.

Cruz *et al*. (1999) found that flowering was negatively affected by soil moisture stress in the west Amazon region of Brazil at a site with a 6 month dry season. He found that flowering decreased almost linearly from 59 flowers/m^2 in March to 1 flower/m^2 in August, due to the advancement of the dry season. It was observed in the present study that flowering responds very rapidly, generally in a couple of days, when soil moisture is replenished by rains, and provided that air temperature is not too low.

Ibrahim (1994), working with *A. pintoi* in Costa Rica found a period of low flowering from November to February and a period of higher flower production in the remaining part of the year. Increasing stocking rate from 1.75 to 3.0 animal units (AU)/ha increased flowering from about 55 to about 85 flowers/m^2. In the present study, the maximum was ten times as high (851 flowers/m^2 for June, 1999) than the maximum reported in Costa Rica, but in the present study, the minimum was zero from December to February.

It is very difficult to separate the effects of photoperiod, irradiance or heat-unit accumulation on flowering (Bell *et al*., 1991). Valls and Simpson (1994) mentioned that flowering depends strongly on day length, with 12 h being the critical minimum (Ketring, 1979). However, this may not apply to all *Arachis* species, since most studies were based on groundnut (*A. hypogea*) which is far from conclusive, with reports of groundnut being a facultative short day plant (Bagnall and King, 1991). Argel and Pizarro (1992) stated that *A. pintoi* has a day-neutral photoperiod response. In the present study, flowering was either scarce or absent from December to February, even though there was good rainfall. Guápiles, Costa Rica (10° 13' Lat. N), the site of Ibrahim (1994) research has a day length equal or longer than 12 h from 9 March until 6 October (212 days). At the site of the present study (20° 03' Lat. N) the period of day length equal or larger than 12 h starts on 15 March and ends in 30 September (200 days). In the Costa Rican site, flowering slumped, but did not cease, during the period of reduced day lengths, whilst in the site of the present study flowering ceased almost completely during the same period of the year. This suggests that low winter temperatures may also have a negative effect on flowering, winter temperatures being higher at the Costa Rican site than at the site of the present experiment.

In Costa Rica Ibrahim (1994) found that high stocking rates enhanced the stoloniferous habit of *A. pintoi*, in the same way the stocking rate used in the present experiment, stimulated stolon production. Seed numbers increased with time, from close to 900,000 seedpods/ha in March 1998 to 8,500,000 seedpods/ha in September 2000, which represented a little more than an eight-fold increase in a period of 36 months. This is a quite large increase compared to that reported by Jones (1993) for a podzolic soil in Australia, which was four-fold from August 1987 (1,070,000 seedpods/ha) to August 1992 (4,700,000 seedpods/ha).

In the Cerrados of Brazil, *A. pintoi* accession CIAT 17434 yielded 348 kg of seedpods/ha in 19 months (Pizarro *et al*., 1997). In the West Amazon region of Brazil, Cruz *et al*. (1999) found that from 13 to 18 months after planting the mean seedpod yield was 937 kg/ha, a higher level than the highest found in the present study.

Seed reserves were low the first two years and then increased considerably by the third year. The same behaviour, but in a shorter time span, was recorded by Pizarro *et al*. (1998) in Planaltina, Brazil in a site with 1500 mm of rainfall/year, 22 °C of mean annual temperature. Seedling survival was extremely low, nil to less than 1%. In contrast, Jones (1993) in Australia found half-lives ranging from 3 to 35 months for different soil types.

The regeneration capacity of *A. pintoi* increased with time, particularly under the heavy instantaneous grazing used in the present study. While this may increase legume persistence, it may also lead to overcrowding of companion grasses by the legume, which is undesirable, because in monoculture *A. pintoi* has lower DM yields than when it is mixed with grasses and it may lead in time to weed invasion due to the high N status of the soil (Hernández *et al*., 1990; Valles *et al*., 1992). It was also shown that *A. pintoi* is just as persistent a legume when established in non-cultivated existing native pasture as in fully cultivated mixed grass-legume pastures. It opens wider possibilities for the improvement of native pastures with *A. pintoi* at much lower cost than would be the case with full cultivation.

3. 5 Conclusions

1. The strong stoloniferous habit of *A. pintoi* CIAT 17434 led to high levels of flowering and soil seed reserves.
2. Management strategies must be devised to keep sward legume levels around 30%, in order to keep a high potential for DM production from the sward.

4

STANDING DRY MATTER AND BOTANICAL COMPOSITION OF NATIVE GRASS/*Arachis pintoi* CIAT 17434 AND NATIVE GRASS PASTURES IN THE HUMID TROPICS OF MÉXICO

4. STANDING DRY MATTER AND BOTANICAL COMPOSITION OF NATIVE GRASS/*Arachis pintoi* CIAT 17434 AND NATIVE GRASS PASTURES IN THE HUMID TROPICS OF MÉXICO

4. 1 Introduction

Nitrogen is the driving force of pasture growth and in consequence, dry matter (DM) production (Whiteman, 1980). However, chemical fertiliser N sources are expensive and not environmentally friendly because its production requires a considerable oil-derived energy, with the related dangers of environmental pollution (UNEP, 1996). For this reason, the importance of using legume-based pastures for sustainable animal production has been much emphasised (Mannetje, 1997).

Animal productivity from native pastures is low in the Mexican tropics and it does not fulfil the milk and meat demand at the regional level (Aluja and Mc Dowell, 1984). This indicates the necessity to augment the production of milk and calves in the dual-purpose farm. This objective can only be achieved through: a) increased standing dry matter (SDM) to allow higher stocking rates and b) highly nutritious DM to improve individual animal performance.

The benefits of associating legumes with grasses have been documented in tropical humid and sub-humid regions of the world. One benefit is the improvement of the diet consumed by the grazing ruminant (Minson, 1990). Another important benefit is the increased soil fertility that results from the biological nitrogen fixation (BNF) by the legume, that would eventually lead to increased pasture growth and SDM (Mannetje, 1997).

This chapter deals with the effect of introducing the legume *Arachis pintoi* CIAT 17434 into a native grass-based pasture of the coastal plains of the Gulf of Mexico, in the State of Veracruz, Mexico, on the SDM and its botanical composition during a 3 year period.

4. 2 Materials and methods

This study was done from January 1998 to December 2000, at the Centre for Teaching, Research and Extension of Tropical Animal Science of the Faculty of Veterinary Medicine and Zootechnics of the National Autonomous University of México. A description of the Centre's location, climate and soils is given in Chapter 2 of this thesis. Minimum and maximum air temperatures under shade and rainfall were recorded daily between 7:00 and 9:00 AM from 1998 to 2000.

The experiment had two treatments (T): The native grass pasture (NG) and NG into which *A. pintoi* (CIAT 17434) was introduced (NG+Ap) into two 2.5 ha fields, the first in 1996 and the second in 1998. The data reported in this chapter relates to the period 1998 to 2000 in field 1. *A. pintoi* was planted between August and November 1996. Glyphosate was applied on 25 cm bands 1 m apart in order to reduce competition to the legume from existing vegetation. The legume was planted from 3 to 7 days after herbicide application, working into the soil 2-3 stolons of 20-25 cm length, with a separation of 0.5 m between planting points within a row. The pasture was not grazed until May 1997, but has remained stocked since that time.

The 2.5 ha pasture was divided permanently into 7 divisions and each division further divided into three temporary subdivisions (1190.5 m^2 each), which gave 21 subdivisions (Paddocks, P), each one grazed for 1 day with a recovery period of 20 days.

Five resident cows grazed on each pasture, but 3 extra cows were introduced between June and August to consume excess forage the resident cows could not consume during the high forage production season. The stocking rate was 2 cows/ha from February-March to August-October and 3.2 cows/ha for the remaining time, which represented instantaneous stocking rates of 42.0 and 67.2cows/ha/day, respectively.

On each pasture treatment 6 paddocks were chosen for sampling for SDM and botanical composition. From the beginning of the study 3 of the NG+Ap paddocks had a larger content of *A. pintoi* in the sward than the other 3 paddocks. Sampling started in January, 1998 and continued until December, 2000.

SDM (kg of DM/ha) was estimated using the comparative yield method (CYM) of Haydock and Shaw (1975); each paddock was sampled every 21 days, in accordance to the fixed rotational grazing schedule. The botanical composition (BC, % of DM of each component) was estimated four times a year in March, June, September and December, using the dry weight rank (DWR) method of Mannetje and Haydock (1963). One hundred quadrats per paddock were rated for SDM and BC when both measurements coincided. In the SDM sampling the forage of reference quadrats was cut to soil level, and dried in a forced-air oven for 48-72 h at 62 °C to determine DM content.

The components of the BC considered were: *A. pintoi* (AP), native grasses (NG), introduced grasses (IG), broad-leaved weeds (BW), narrow-leaved weeds (NW), and native legumes (NL). The NG components of practical relevance for the present study were Bahia grass (*Paspalum notatum*), *P. dilatatum*, *P. plicatulum*, *P. conjugatum*, Matt grasses (*Axonopus affinis* and *A. compressus*), Bermuda grass (*Cynodon dactylon*) and *Setaria* spp. The IG had only two components: Star grass (C*ynodon nlemfuensis*) and Tanner grass (*Brachiaria radicans*), both remnants of late 80's and early 90's plantings. Bitter grass (*P. virgatum*), Savanna grass (*Sporobolus spp*) and *Cyperus* spp. were the main components of the NW group. The main components of the BW were Broom weed (*Sida acuta*) and the legumes *Mimosa pudica* and *M. pigra*. The NL group consisted of species of the genera *Desmodium*, *Mimosa*, *Rhyncosia* and *Centrosema*.

The variances of the SDM as well as each botanical component were statistically analysed with a linear additive model which had the effects of treatment (T), year (Y), Month (M) and Paddock (P). The T effect was tested with the P within T variation as an error term, whilst the main effects of Y, M and all interactions were tested against the residual variation. Percentages were transformed to arcsine(√percent/100) values to normalise the error distribution (Steel and Torrie, 1980). Previous analyses showed the linear effect of time to be significant only on AP and NG of the NG+Ap treatment. These components were related by the equation: Y = a - bX, where 'Y' is the content of NG (%), 'b' is the coefficient of regression and 'X' is the content of AP. Analyses of variance were done with the Statistical Analysis System (SAS, 1989). The Sigma Plot software (SPSS, 1997) was used for linear regression fitting.

4. 3 Results

Rainfall in 1998 (2157 mm), 1999 (2064 mm) and in 2000 (1857 mm) did not differ much from the average of 1915±356 mm per year for the period 1980-1997. For the study period the lowest amount of rain was 7 mm in May 1998 and the maximum was 816 mm in October 1999. Respective mean minimum and maximum temperatures (°C) were 30.1 and 19.3 for 1998, 29.9 and 18.5 for 1999 and 29.9 and 18.7 for 2000. The lowest and highest means for the minimum temperature were 12.9 for January 1999 and 23.7 for June 1998, respectively; the lowest and highest means for maximum temperature were 22.7 for December 2000 and 36.5 for June 1998, respectively. Coefficients of variation for monthly means (averaged across years) ranged from 27% to 100% for rainfall, 0.9% to 11% for minimum temperature and 0.8% to 7% for maximum temperature (Figure 4. 1).

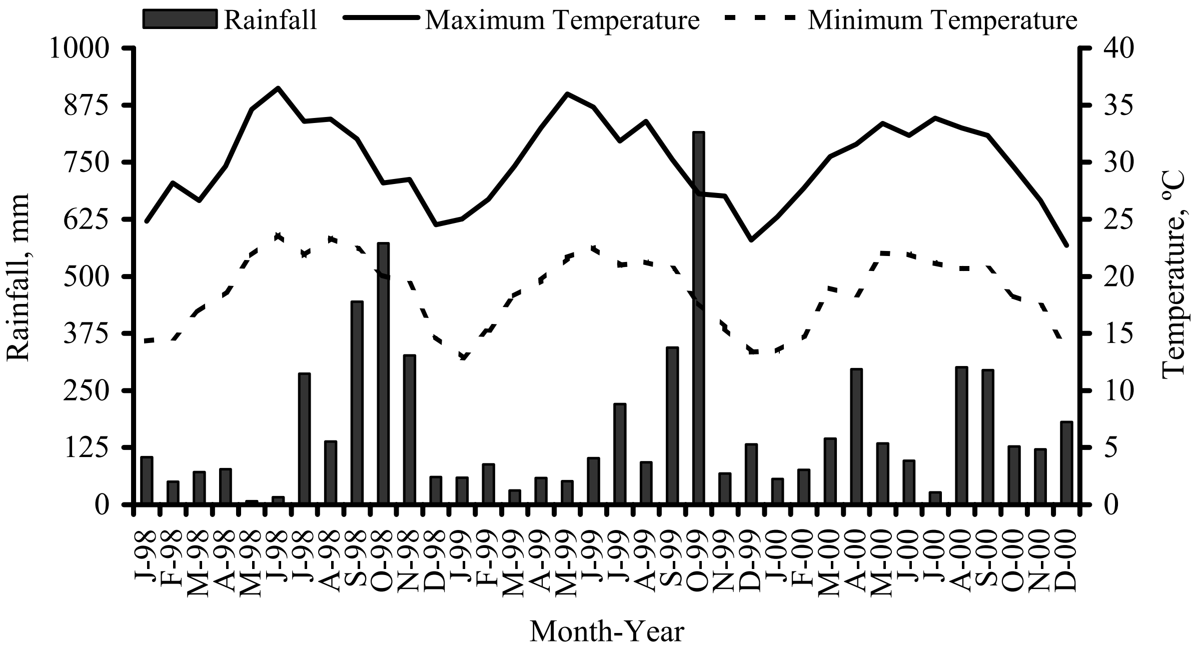

Figure 4. 1. Monthly rainfall and maximum and minimum monthly temperatures at the experimental site from January 1998 to December 2000.

The average ± standard deviation of SDM was 3364 ± 446 kg of DM/ha. The comparison between NG and NG+Ap was highly significant (P=0.0001) within each study year, but of a different magnitude each year, which lead to a highly significant T x Y interaction (P=0.0001; Table 4. 1). The SDM was highly seasonal (Figure 4. 2).

Table 4. 1. Comparison between NG and NG+Ap within year of study, for standing dry matter (SDM, kg DM/ha). Figures are means ± standard errors.

Year	Treatment		Comparison significance (P)
	NG	NG+Ap	
1998	3233 ± 47	3758 ± 47	0.0001
1999	2999 ± 46	3893 ± 46	0.0001
2000	2889 ± 47	3301 ± 47	0.0001

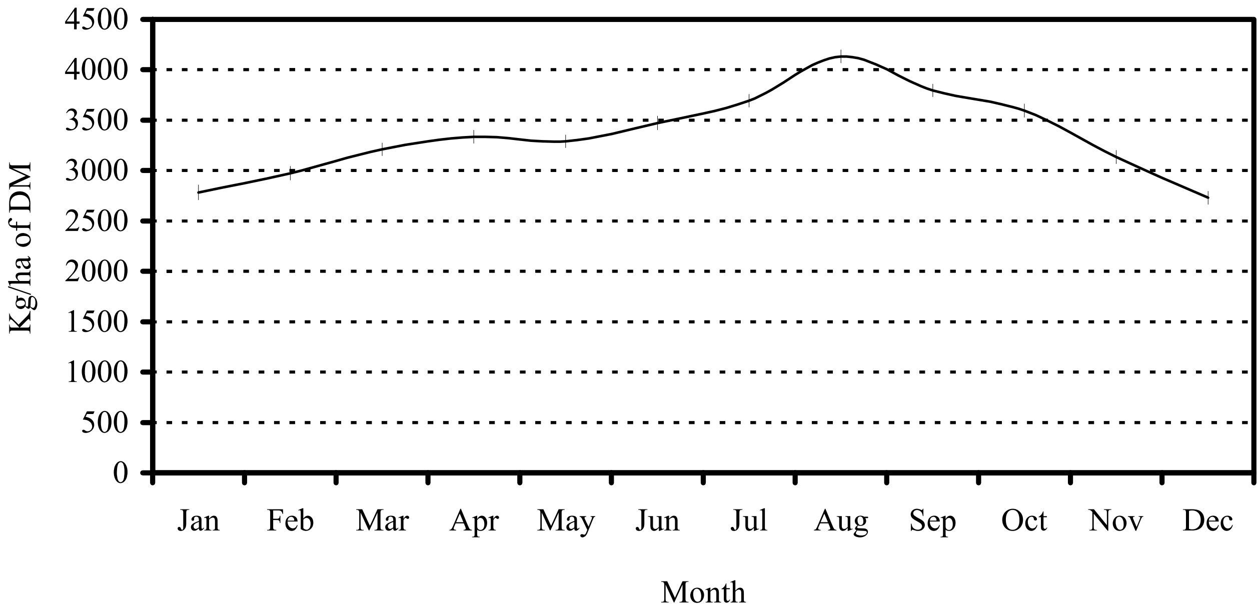

Figure 4. 2. Monthly standing dry matter before grazing (SDM, kg DM/ha) averaged across treatments and years. The vertical bars represent the standard errors.

The main effect of T was highly significant (P=0.0002) on the component NG, and significant (P=0.0211) on NW, but it was not significant on the other botanical components (Table 4. 2)

The main effect of Y was highly significant or significant on all botanical component variables, except on IG (P=0.7172). Year means showed that AP and IG increased with time, while the contrary was shown by NG. The BW, NW and NL components also decreased from 1998 to 2000 but the tendency was not as strong as that of NG (Table 4. 3).

Table 4. 2. Botanical composition (% of SDM) before grazing of native grass (NG) and NG associated with *A. pintoi* (NG+Ap). Figures are means ± standard errors.

Botanical component	Treatment		Comparison significance (P)
	NG	NG+Ap	
A. pintoi (AP)	-------------	25.5 ± 2.0	----------
Native grasses (NG)	68.5 ± 1.1	46.0 ± 1.4	0.0002
Introduced grasses (IG)	8.0 ± 0.8	5.4 ± 0.8	0.0523
Broad-leaved weeds (BW)	13.8 ± 0.8	12.4 ± 0.8	0.5135
Narrow-leaved weeds (NW)	4.6 ± 0.6	7.2 ± 0.6	0.0211
Native legumes (NL)	5.1 ± 0.3	3.5 ± 0.5	0.0857

Table 4. 3. Effect of year on the botanical composition of native pastures in association with *A. pintoi*. Figures for Ap are means ± standard errors of the NG+Ap treatment and for the other botanical components of the NG + Ap and the NG treatments.

Botanical component	Year		
	1998[1, 2]	1999[1, 2]	2000[1, 2]
Arachis pintoi (AP)	14.7 ± 2.4 [a]	25.2 ± 3.3 [b]	36.6 ± 3.9 [c]
Native grasses (NG)	59.8 ± 1.7 [a]	56.9 ± 2.4[ac]	54.7 ± 2.6[bc]
Introduced grasses (IG)	6.0 ± 0.9 [a]	6.6 ± 1.2 [a]	7.1 ± 1.0 [a]
Broad-leaved weeds (BW)	15.8 ± 1.1 [a]	11.4 ± 0.8[bc]	12.2 ± 1.0 [c]
Narrow-leaved weeds (NW)	6.1 ± 0.8 [a]	7.5 ± 0.9 [a]	4.8 ± 0.6 [b]
Native legumes (NL)	5.0 ± 0.6 [a]	5.0 ± 0.6 [a]	3.0 ± 0.4 [b]

1: Means within a row followed by the same superscript are not statistically different (P>0.05).
2: The quantities do not add up to 100% because of rounding and because means for *A. pintoi* were generated with half the number of observations (72 *vs.* 144), since the NG treatment did not have this component.

The magnitude of the difference in NG content between the two treatments increased with the year: 14.9, 24.9 and 28.5 percent units for 1998, 1999, and 2000, respectively (Table 4. 4), which is the reason for the highly significant (P=0.0004) T x Y interaction. The same interaction was significant (P=0.0282) on IG. The difference was not significant in 1998 and 1999, but it was highly significant in 2000 (Table 4. 4). The other botanical components were not affected by this interaction (P>0.05).

Table 4. 4. Combined effect of year and treatment on the contribution to the botanical composition (% of SDM) of native grass (NG) and IG. Figures are means ± standard errors.

Component	Year	Treatment		Treatment comparison significance (P)
		NG	NG+Ap	
Native grass (NG)				
	1998	67.3 ± 1.8	52.4 ± 1.9	0.0001
	1999	69.4 ± 2.1	44.5 ± 2.5	0.0001
	2000	68.9 ± 1.9	40.4 ± 2.6	0.0001
Introduced grass (IG)				
	1998	7.6 ± 1.5	4.4 ± 0.7	0.1097
	1999	6.0 ± 0.5	7.1 ± 2.3	0.5717
	2000	10.3 ± 1.5	3.9 ± 0.7	0.0015

The single effect of M, and the remaining interaction effects did not affect (P>0.05) any of the botanical components.

The NG was the component most affected by the increase of AP in the sward. Sixty six percent of the variation in the content of NG was explained by the content of AP (Figure 4. 3).

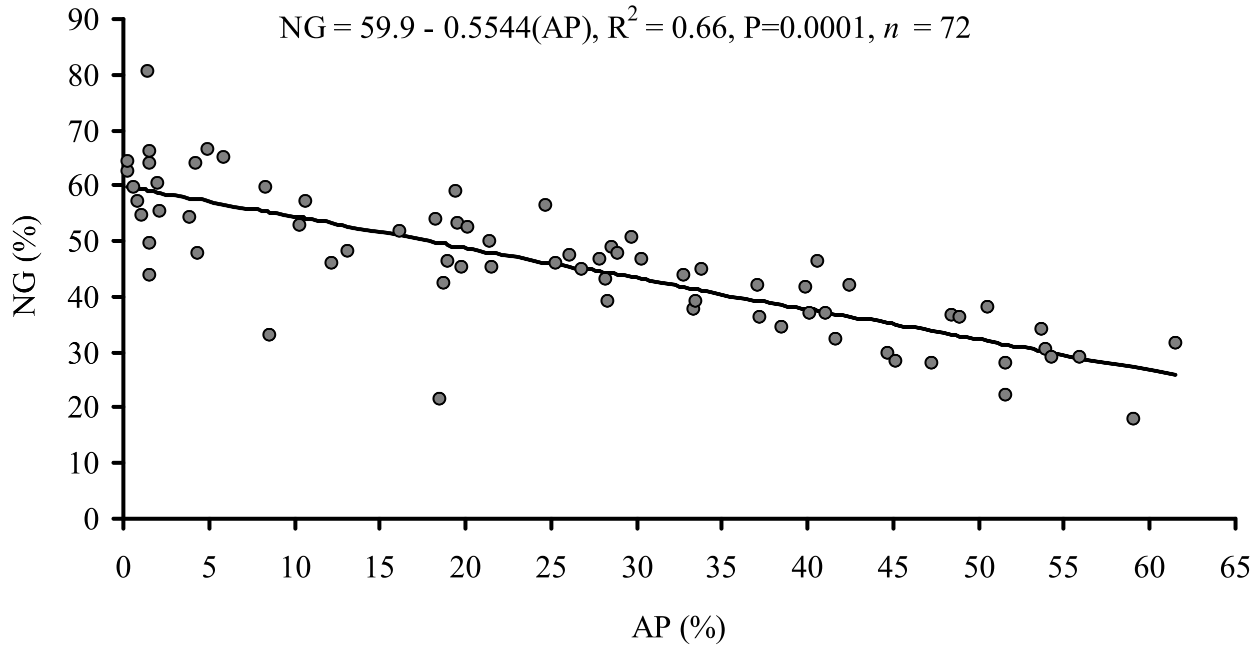

Figure 4. 3. Linear reduction of the native grass component (NG, %), as a function of *A. pintoi* content (AP, %) in the sward.

4. 4 Discussion

The SDM of both treatments showed the seasonal trend in pasture growth previously described for the Centre. From March to June there was a period of low but increasing SDM, then there was a period of high SDM from July to September, which was followed by a decrease to low SDM from November to February. Therefore, the shape of the SDM curve was as expected, with a peak between August and October and a nadir in December or January. The difference between January and August SDM means was about 1400 kg of DM/ha, and about 1500 kg of DM/ha between August and December. This trend was the basis on which it was decided to use seasonal mating for the commercial dual-purpose herd, which eventually leads to an increased stocking rate during the period of highest DM production. According to a multiple mean comparison ("t" test, data not shown), there were not two months alike throughout the year with respect to SDM. The detection of small differences between monthly means, was due to the large number of observations generated in the 3 years of study, which led to low standard errors (Figure 4. 2).

Rainfall decreased from 1998 to 2000 and SDM in the NG treatment decreased accordingly, but the decrease was only 5.8%, which is too low to have an impact on animal production on a whole-year basis. In the association, the SDM decreased 7.2% from 1998 to 2000. Also too low to be of biological significance.

SDM decreased with time while at the same time the legume component increased mostly at the expense of the NG component. This suggests that too much legume in the sward could lead to reduced SDM values, mostly due to the inability of NG grasses to use efficiently the higher N content of the soil induced by *A. pintoi* N-fixation, to increase pasture growth. Tropical native grass-based pastures, in which *Paspalum* spp. dominate, respond less to applied N than introduced grasses (Johnson *et al*., 2001). The replacement of C_4 grasses by C_3 legumes, with a lower DM yield potential (Ludlow, 1985), can also lead to reduced SDM of the association. Within each month, the treatment mean for NG+Ap was almost always higher than NG mean, but not always was this difference significant (P>0.05). This, is in accordance with the T x Y interaction, and also shows that the environmental effect was stronger than that of treatments.

The SDM level depends on factors like pasture growth and senescence rates and the level of intake by the animals. This makes difficult the comparison of SDM values from pastures from different sites with distinct soils, climates and grazing management. However, published values are the framework within which the benefits of novel pasture species can be judged.

Gonzalez *et al.* (1996) in Costa Rica, found that during 2 productive cycles the Star grass (*Cynodon nlemfuensis*)/*A. pintoi* CIAT 17434 association yielded more DM/ha (3.3 to 4.0 t of DM/ha) than the grass alone (3.0 to 3.5 t of DM/ha). These values were close to those of the present investigation: 3.0 and 3.7 t of DM/ha for the NG and NG+Ap treatments, respectively. However their stocking rates, 2.9 AU/ha in 1990 and 2.4 AU/ha in 1991-1992 were higher than those used in the present study, because of the higher potential for forage production at the Costa Rican site as result of more fertile soils and a higher rainfall (> 4000 mm/year).

The DM yields of *A. pintoi* respond to differences in soil and climate. In a Costa Rican site, in the humid tropics with moderate to high soil fertility, *A. pintoi* yielded more (4.1 t/ha) than at a site in Ecuador (2.4 t DM/ha), also in the humid tropics, but with a low fertility soil (Argel and Pizarro, 1992). The site of the present study does not appear to present rainfall limitations, but the low fertility of the soil may be the real limitation to a higher SDM of either treatment. Also, the low SDM may reflect a lower potential to produce DM of the NG component of the pasture treatments, as compared to the potential of introduced species.

Persistence and spread of trailing legumes like Siratro or *Centrosema* spp, depends mainly on the longevity of mother plants with very little recruitment even at low stocking rates (Eng *et al*., 1978; Mannetje and Jones, 1990), which contrasts with the highly persistent *A. pintoi*, whose strong stoloniferous habit and high levels of soil seed reserves assure persistence (Ibrahim, 1994; Chapter 3 of this Thesis).

In the Colombian savanna ecosystem, the 5 year average content of *A. pintoi* in association with *B. decumbens* was 50% in the rainy season and 16% in the dry season. The respective values for a *B. humidicola*/*A. pintoi* association were 29% and 12%. In both cases the initial content of the legume was 20% (Rincón and Argüelles, 1991).

Van Heurck (1990) found the same contents of Stargrass and *A. pintoi* (44%) when these were grown in association under grazing for 4 years. Contents of weeds (4%) and native grasses (8%) were marginal. In contrast, the Stargrass “monoculture” had significant contents of weeds (10%) and volunteer native grasses (39%).

The content of the legume in the rainy season in Colombia responded positively to stocking rate in a *B. humidicola*/*A. pintoi* association, from an initial average of about 5% for all stocking rates, it increased to around 11%, 16% and 18% for 2, 3 and 4 animals/ha, respectively, in 3 years, to decrease in the fourth year to 6%, 9% and 14% (CIAT, 1991).

Ibrahim (1994) reported that an increase in stocking rate from 1.75 to 3.0 AU/ha increased the content of *A. pintoi* in association with *Brachiaria brizantha* from 20% to 33% and with *B. humidicola* from 11% to 20. His results indicated certain stability of the *A. pintoi* in the low stocking rate, while at the high stocking rate *A. pintoi* showed a strong tendency to increase. In the *B. humidicola* association the weed content increased to the point that *B. humidicola* was replaced by gamelote (*Paspalum fasciculatum*).

González *et al*. (1996) in Costa Rica showed that the *A. pintoi* content of Stargrass/*A. pintoi* association, was around 41% from January 1990 to July 1992, but there were noticeable changes with time. In the first 9 months (January to September 1990), *A. pintoi* grew steadily from 19% to 63%. In the same period Stargrass plunged from 64% to 34% and natural grasses from 12% to 4%, while the weed content was low and uniform. *A. pintoi* declined to 35%, and Stargrass to 39% in July 1992, while the natural grasses increased from to 29%, occupying the space left by the decreasing components, since the weed content was constantly low.

In the present experiment 3 paddocks had very low initial *A. pintoi* content (< 1%) and another 3 paddocks had moderate contents (18%). *A. pintoi* increased by 0.7% per month in the former, and by 1.1% per month in the latter, which at the end of the trial resulted in 24% and 57% of *A. pintoi* for paddocks with low and high initial *A. pintoi* contents, respectively. These levels of *A. pintoi* coincided with those found by Ibrahim (1994) and that for the first period of measurements by González *et al*. (1996).

In the present study, the increase of *A. pintoi* in the botanical composition occurred at the expense of the other components, mainly NG. When *A. pintoi* was absent, the estimated NG content was about 60%. About 1.8 percentage units of *A. pintoi* replaced a percent unit of NG. To use a linear relationship between both components is simple and easy to interpret and can be useful to examine one-to-one competition among sward components, particularly if it is applied to different management situations, in a similar way as that proposed by Ennik (1981).

4. 5 Conclusions

1. The environmental effect, represented by the effect of year, had a more pronounced effect on SDM than the effect of treatment.
2. The NG+Ap pasture out-yielded the NG pasture throughout the trial, but the yields of the former decreased faster with time than those of the latter.
3. Linear regression among contents of sward components is an alternative to analyse one-to-one component competition in experiments which were not laid down for such purposes.
4. These findings confirm the great capacity of *A. pintoi* to persist and its aggressiveness under grazing conditions.

5

CHANGES IN SOIL VARIABLES AFTER THE INTRODUCTION OF *Arachis pintoi* INTO A NATIVE PASTURE IN THE HUMID TROPICS OF MÉXICO

5. CHANGES IN SOIL VARIABLES AFTER THE INTRODUCTION OF *Arachis pintoi* INTO A NATIVE PASTURE IN THE HUMID TROPICS OF MÉXICO

5. 1 Introduction

In Chapter 2 of this thesis the introduction and establishment of *A. pintoi* was discussed and chapter 3 dealt with its persistence. This chapter describes the effects of *A. pintoi* on soil variables that are indicators of sustainability of the pasture agroecosystem (Westerhof *et al*., 1999). This is of importance because the sustainable improvement of existing native pastures relies on the use of persistent legumes that enhance soil fertility as well as sustainable animal production.

5. 2 Materials and methods

In Chapter 2 the geographic location, climate and soil type of the study site were described. The present experiment was carried out on native grass pastures and had two treatments: a native grass pasture (NG) and NG into which *A. pintoi* CIAT 17434 was planted (NG+Ap). The first field (field 1) of the association was established between August and November 1996. Glyphosate was applied in narrow (25 cm) bands, 1.0 m apart, to kill standing grass vegetation. Two weeks after that, stolons were planted along the bands distances of 0.5 m. Field 1 was lightly and intermittently grazed from May to August, 1997. From then on grazing has continued without interruption. The second field (field 2) of the association was established in November, 1999. In this case, the area (2.5 ha) was heavily grazed by 60 adult F1 (Holstein x Zebu) cows for seven days before introducing *A. pintoi*. Stolons were directly planted into the sward, without the use of herbicide, in rows 1.0 m apart at distances of 0.5 m.

Rotational grazing, with 1 day of grazing and 20 days of rest, was used. Stocking rate was 2 cows/ha during periods of low pasture productivity and 3.2 cows/ha at other times. The reduction of stocking rate took place when by the end of the year or beginning of the next year, the standing dry matter (DM) yield fell below 2500 kg /ha on any of the sampled paddocks.

Soil sampling took place once per year from 1998 till 2001. In March 1998, bulk samples of the whole area were taken to depths of 0-15 cm and 15-30 cm and analysed for sand, silt, clay, pH, organic C, N and P. A 2.5 cm soil auger was used; ten auger samples made up one soil bulk sample of which 3 were obtained per depth. This sampling was not included in the statistical analysis (Table 5.1). In August 1999 a pasture next to the experimental pastures was sampled to a depth of 30 cm in order to have a reference value of available P and the cation exchange capacity (CEC) (Table 5. 2).

Table 5. 1. Soil characteristics measured on triplicate bulk samples from field 1 taken at 0-15 cm and 15-30 cm depth in March 1998. Values are means ± standard deviations.

Variable	Soil Depth, cm	
	0 - 15	15 -30
Sand	40.09 ± 4.45	38.09 ± 5.65
Silt	32.85 ± 8.36	31.52 ± 4.09
Clay	27.05 ± 5.98	30.39 ± 4.83
pH	5.41 ± 0.31	5.37 ± 0.28
C	1.02 ± 0.44	0.78 ± 0.15
N	0.13 ± 0.06	0.10 ± 0.04
C:N Ratio	7.85 ± 2.04	7.80 ± 2.03

In April 1999 and September 2000, 42 soil samples were taken from each of the four pasture ‘treatment x field’ combinations systematically over the total area. In March 2001, only three sub divisions were used; three samples were drawn from each division and bulked into one for soil analysis of pH, C and N. The samples were air dried at room temperature, the roots removed, and the soil ground to pass a 2 mm sieve, prior to laboratory analysis.

Table 5. 2. Soil characteristics measured on duplicate bulked samples from a pasture adjacent to field 1, taken to a 0-30 cm depth in August 1999.

Variable	Mean ± Standard deviation
Sand, %	34.00 ± 4.24
Silt, %	26.00 ± 4.24
Clay, %	40.00 ± 8.49
pH 1:2, water	5.40 ± 0.21
pH 1:2, 0.01 M $CaCl_2$	4.30 ± 0.21
P-Olsen, ppm	3.50 ± 0.70
P-Bray, ppm	2.00 ± 1.40
H^+, meq/100 g	0.25 ± 0.05
Al^{3+}, meq/100 g	0.29 ± 0.40
Ca^{2+}, meq/100 g	7.17 ± 0.81
Mg^{2+}, meq/100 g	2.17 ± 0.03
K^+, meq/100 g	0.33 ± 0.04
Na^+, meq/100 g	0.32 ± 0.16
CIC, meq/100 g	10.51 ± 1.41
Base saturation, %	95.20 ± 3.66
Total acidity, %	4.80 ± 3.66

Bulk density was determined in 1999 and 2000 samplings. A steel corer of 50 mm internal diameter and 50 mm in height was used. The sampling site was cleaned to expose the bare surface, and then the auger driven through the soil. The soil around the auger was dug out and the soil below the auger bottom was separated with a sharp knife. The auger with the soil in it were dried in a forced air oven. Soil bulk density (BD) was expressed as g/cm^3 (Anderson and Ingram, 1993).

Soil pH was measured on a 2:1 water:soil slurry prepared with distilled water, using a conventional glass electrode pH meter.

Soil organic carbon concentration was analysed by the method of Walkley and Black (1934) and expressed as % of the dried soil (C, %). Soil organic matter (OM, %) was calculated by multiplying C by the Vammelen factor of 1.724, which assumes a content of 58% of C in the soil OM (Anderson and Ingram, 1993). Total organic carbon (Cp) was expressed as kg/ha for the 0-20 cm depth by the following equation:

$$Cp\ (kg/ha) = (100 \times 100 \times 0.2) \times BD \times C/100$$

where (100 x 100 x 0.2) is the volume of soil in an hectare to a depth of 0.2 m, BD is the bulk density of the soil in kg/m^3, and C is the soil organic carbon concentration in %. This calculation assumed that the BD in the 0-5 cm depth was representative of the 0-20 cm depth at which soil samples for laboratory analyses were taken.

The N content of the soil was measured by the Kjeldahl method and it was expressed as % of the dried soil. Total N (Np) was expressed as kg/ha for the 0-20 cm depth, by a similar equation as that used to calculate Cp, in which C was substituted by N.

The variances of the response variables were statistically analysed with a model that included the effects of treatment (GN and GN+Ap), year (1999 and 2000) and its interaction, and the variation between pasture divisions within each 'pasture x year x field' combination was used to test those effects. Soil data for 2001 were analysed separately with the effects of treatment, and pasture division within treatment as error term.

5. 3 Results

Pasture treatment ha no significant effect on BD. The mean bulk density of the soil highly significantly (P=0.0001) decreased from 1.27 ± 0.14 g/cm in 1999 to 1.15 ± 0.14 g/cm^3 in 2000, a relative decrease of 10%. (Table 5. 3).

Table 5. 3. Orthogonal comparison of pasture treatment (NG and NG+Ap) means (± std. err.) in 1999 and 2000.

Soil variable	1999			2000		
	NG	NG+Ap	Sig.[1]	NG	NG+Ap	Sig.[1]
Bulk density (g/cm^3)	1.25 ± 0.01	1.28 ± 0.02	0.1099	1.14 ± 0.02	1.17 ± 0.01	0.0853
Soil reaction (pH)	4.99 ± 0.03	5.09 ± 0.03	0.0158	5.16 ± 0.03	5.21 ± 0.03	0.2210
Organic matter (%)	2.47 ± 0.07	2.69 ± 0.09	0.0214	2.42 ± 0.07	2.51 ± 0.07	0.3703
Organic Carbon (%)	1.43 ± 0.04	1.56 ± 0.05	0.0212	1.41 ± 0.04	1.46 ± 0.04	0.3777
Nitrogen (%)	0.1375 ± 0.0010	0.1452 ± 0.0077	0.0001	0.1218 ± 0.0105	0.1205 ± 0.0105	0.0374
C:N ratio	13.00 ± 0.71	13.19 ± 0.78	0.0286	17.19 ± 1.21	18.74 ± 1.35	0.0584
Carbon amount (kg/ha)	35683 ± 1128	39865 ± 1492	0.0058	32067 ± 1127	34179 ± 1033	0.1618
Nitrogen amount (kg/ha)	3558 ± 256	5562 ± 447	0.0001	2311 ± 192	3049 ± 256	0.0324

1: Significance of the difference between treatments within year.

The pH of the soil was not affected by pasture treatment (P=0.0827). Although the difference in pH was relatively small between years: 5.04 ± 0.28 in 1999 *vs.* 5.18 ± 0.28 in 2000, the main effect of year was highly significant (P=0.0013) (Table 5. 3). The soil pH values were similar between treatments in 2001 (Table 5. 4).

The mean C content of the soil was not significantly affected by pasture treatment or year (Table 5. 3). The NG+Ap pasture contained significantly (P=0.0412) 9.3% more Cp than NG. Cp was highly significantly (P=0.0032) 14% lower in 2000 than in 1999. However, this difference cannot be explained. The interaction pasture x year was not significant (Table 5. 3). In 2001 C content was similar between treatments (Table 5. 4)

Table 5. 4. Orthogonal comparison of pasture treatment (NG and NG+Ap) means (± std. err.) in 2001.

Soil variable	Pasture		$P > F^1$
	NG	NG+Ap	
pH	5.57 ± 0.23	5.43 ± 0.10	0.2305
Organic matter	2.35 ± 0.49	2.90 ± 0.49	0.0708
Carbon	1.36 ± 0.28	1.68 ± 0.28	0.0704
Nitrogen	0.14 ± 0.01	0.16 ± 0.02	0.0266
C:N	9.67 ± 1.52	10.42 ± 1.21	0.4101

1. Significance of the difference between treatments.

The soil in the NG+Ap pasture had a highly significantly (P=0.0002) 42% higher N concentration than the NG pasture in the top 20 cm. The larger mean N content in 1999 than in 2000 cannot be explained (Table 5. 3). In 2001, the difference in soil N concentration between treatments were small, but significant (Table 5. 4). The NG+Ap pasture had highly significantly (P=0.0001) 47% more N in the top 20 cm of soil than the native grass pasture. Np was significantly affected by the treatment x year interaction (P=0.0449), because the difference between pastures was higher in 1999 than in 2000 (Table 5. 3).

The mean C:N ratio for the NG+Ap pasture was significantly (P=0.0224) lower than that for the NG pasture. The ratio was highly significantly (P=0.0017) lower in 1999 than in 2000. (Table 5. 3). In 2001 the C:N ratio was lower than in the two previous years but differences between treatments were negligible (Table 5. 4).

5. 4 Discussion

Soil quality has been defined as: "The capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Soil Science Society of America, 1997). The assessment of soil quality implies matching the current soil properties with those needed by the selected land use. A low fertility does not necessarily mean a low quality. A low fertility soil as the one of the present experiment (Tables 5. 1 and 5. 2) is well suited for native grass pasture productivity, because the mixture of native species is well adapted to the low levels of nutrients in the system.

Maintaining or increasing the stores of C and N in response to greater yields of biomass, induced by N_2 fixation by the legume, is an environmentally important aspect of pasture production in the tropics, because it implies the long term entrapment of CO_2 and increased soil fertility. A potentially negative effect of N_2 fixation by legumes is that it may acidify the soil in the long term (Haynes, 1983).

Legumes can be useful in reducing soil compaction caused by treading and trampling due to increased stocking rates (Alegre and Lara, 1991). However, BD also depends on organic matter content, soil texture and clay content, and whether the soil is damp or dry when heavy grazing occurs (Reátegui *et al*., 1990; Escobar and Toriatti-Dematté, 1991).

However, the effect of the inclusion of the legume was not detectable in the 3½ years of this study as there was a negligible difference between pasture treatments. Ibrahim (1994) in Costa Rica found that increasing stocking rate from 2 to 3 AU/ha on a *Brachiaria/A. pintoi* mixture slightly increased bulk density from 0.76 g/cm^3 to 0.85 g/cm^3, in the 0-5 cm topsoil layer.

The accumulation of soil N via N_2 fixation by the legume is another important factor. Thomas *et al*. (1997) and Valles (2001) have shown that *A. pintoi* CIAT 17434 derives between 65% to 85% of its N from fixation. These figures and our data indicate that N is accumulating in the soil, increasing the chances of nitrate leaching and soil acidification (Haynes, 1983). Three and a half years after the start of grazing *Ap* based pastures, was too short a time to show effects on pH.

Valles (2001) sampled the soil profile down to 1 m depth of both treatments in the field 1 of our experimental pastures, when *A. pintoi* had been established for 1 year. He did not detect differences (P>0.05) between soil pH through the profiles of the NG and NG+Ap pastures. However, when sites where the legume had been planted 5 and 8 years before were compared with adjacent "control" sites without the legume, at all depths pH was significantly (P<0.05) lower in areas with the legume. In the 5 year old area pH values for the 0-5, 5-15 and 15-30 cm depths for the plots under legume were 5.05 and 5.52, 5.07 and those under grass 5.66, and 5.44 and 5.72, respectively. The differences were slightly lower, but still significant (P<0.05) for the 8 year old pasture. Therefore, there is a potential for future pH decreases as a result of *A. pintoi* inclusion into NG.

Pasture soils accumulate organic carbon with time. The continuous addition of substrate (roots and aerial litter) coupled with N deficiency, as it occurs in permanent unimproved pastures, are the factors responsible for the accumulation of organic matter in these soils (Huntjes and Albers, 1978).

Considering the 1998 value of 18.3 t/ha as the initial Cp for both pastures, the Cp in the soil increased by 6.90 t/ha/y and 7.95 t/ha/y for the NG and NG+Ap pasture treatments, respectively. This represents a considerable gain in C storage by these pasture soils and shows that introducing *A. pintoi* into a native pasture has the potential to sequester C, as has been shown by Fisher *et al*. (1994) in the Colombian savanna region and by Ibrahim (1994) in Costa Rica.

The C:N ratio of the soil is commonly taken as one of the measures of soil quality and a target value of 10 regarded as ideal. The C:N values for the NG+Ap and NG pastures of our experiment were higher, around 13 in 1999 and 17 in 2000, and similar to the target value in

2001(Tables 5.3 and 5.4). Ibrahim (1994) in Costa Rica found C:N ratios on *Brachiaria/A. pintoi* of 12.5, which were comparable to those of the present study.

5. 5 Conclusions

The present study showed that the introduction of *A. pintoi* CIAT 17434 was able to improve the C and N concentrations and amounts in the soil. These are good indicators of the ability of this legume to improve the sustainability of tropical dual-purpose cattle systems by C sequestration and soil fertility increase.

6

PERFORMANCE OF DUAL-PURPOSE F1 (HOLSTEIN X ZEBU) COWS GRAZING A NATIVE PASTURE-*Arachis pintoi* ASSOCIATION IN THE HUMID TROPICS OF MÉXICO

6. PERFORMANCE OF DUAL-PURPOSE F1 (HOLSTEIN X ZEBU) COWS GRAZING A NATIVE PASTURE-*Arachis pintoi* ASSOCIATION IN THE HUMID TROPICS OF MÉXICO

6. 1 Introduction

In the Mexican tropics native pastures are the main feed supply of dual-purpose production systems. They cover about half the tropical grazing lands, and are generally poorly managed. Overgrazing is common during the critical season (November to May) and undergrazing occurs the rest of the year, as forage DM yields are higher than animal demand. It has been consistently reported that under common farming conditions this type of pasture can only support a stocking rate of 1 animal unit (AU) per hectare per year (Aluja and Mc Dowell, 1984).

However, it has been shown (Alarcón *et al*., 1999) that native grass pastures of the experimental station and those of its area of influence may be able to support higher stocking rates than the traditionally used by cattlemen (Corro *et al*., 1999).

Persistent tropical legumes are known to improve pasture dry matter (DM) yield and nutritive quality (Mannetje, 1997). Experiences in Latin America have shown that *Arachis pintoi* appears to be the legume of choice in the humid tropics because it is productive and persistent, particularly under high grazing pressure (Ibrahim, 1994).

A. pintoi has improved animal performance in the humid tropics of Costa Rica, where Hernández *et al*. (1995) recorded the highest liveweight gain so far reported from non-irrigated herbaceous tropical pasture: 937 kg/ha/year on a mixture of *Brachiaria brizantha* and *A. pintoi*, grazed at 6 steers/ha, and cows grazing a Stargrass (*Cynodon nlemfuensis*)-*A. pintoi* association yielded 8.8 kg of milk per day, compared to 7.7 on Stargrass alone (Van Heurck, 1990).

Previous studies on animal performance from *A. pintoi*-based pastures were conducted with sown grasses as companion species. The present chapter reports animal performance of dual-purpose F1 (Holstein x Zebu) cows on a native pasture-*A. pintoi* association in the humid tropics of the State of Veracruz, México.

6. 2 Materials and methods

6. 2. 1 Soils and climate

The location, climate and the soil of the experimental site were described in chapter 2. The climate is hot (23.5 °C mean annual temperature) and humid (mean annual rainfall 1981 mm), with rains all year-round. The Ultisols soils are acid and of low fertility (pH 4.5-5.2, 1-2 ppm of available P).

6. 2. 2 Animals and their management

The management received by experimental animals was as similar as possible to that of the commercial herd of the station, because this facilitated routine activities like weighing, preventive medicine measures and herd reproductive plans.

The cows were of the F1 cross (Zebu cows x Holstein bulls), that were inseminated with semen of beef breed bulls to produce a 3-breed cross calf. The calving period was from March to July each year, so calving and first months of lactation coincided with the period of higher pasture growth to have enough pasture available for the cows to be in a good condition (body condition score $\geq$2.5, on a 1 -5 scale) at the beginning of the mating period (July to October). Whether the cows cycled or not, in July and August hormonal drugs were administered to synchronise oestrus and then the cows were artificially inseminated (AI) in September after natural oestrus was observed. In October, bulls were turned-out with the herd to cover cows that did not become pregnant with AI. The cows left temporarily the study for 3 days to facilitate oestrus observation after synchronisation. During the first week after calving, calves suckled at will and if needed, cows were hand milked to “relieve” the udder. From the second week after calving, cows were machine milked once a day at 8:00 AM and their milk yield recorded.

Drying-out occurred when daily milk yield was < 3 kg, or around the last week of January, to avoid excessive weight loss and to keep pace with the one year production cycle. One kg of molasses DM was administered per head/day. The cows were weighed monthly, just after milking and suckling, but without fasting.

The calves were allowed to suckle all four teats for half an hour after milking and suckled again for half an hour at 2:00 PM in 1998, 1999, and 2000 while in 2001 no suckling took place in the afternoon. In the morning 2 teats in 1998 and 1999 and 1 teat in 2000 and 2001 were not milked but left to the calves, along with the residual milk in the milked teats. The calves grazed separately from their dams on Stargrass (*Cynodon nlemfuensis*) pastures at a stocking rates from 3 to 4 AU/ha. The calves concentrate (12-14 % CP) intake increased with age, but it was on average 0.9 kg of DM/calf/day from one week of age until weaning at 4 months of age.

Every week calves were weighed before and after suckling in order to estimate milk intake as well as average daily gain. They were not fasted prior to weighing to avoid changing their feeding habits. Suckling and weighing were done under shelter, to prevent weight gain due to rainwater kept in hair or weight loss from moisture loss through panting. In general, calves had produced droppings and urinated by the time the weighing-suckle-weighing technique was applied, so this did not affect calculations of milk intake.

6. 2. 3 Pasture establishment and management

Prior to this experiment, the Stargrass pastures were fertilised annually with N (184 kg/ha) and P (20 kg/ha) and rotationally grazed (7 days grazing and 28 to 35 days recovery), between 1980 and 1990. In 1991 fertilisation was discontinued, but some maintenance N (23 kg/ha) was applied in 1993 and 1995. A rapid rotation was adopted with 1 to 3 days of grazing and 35 (rainy season) to >70 days (critical season) of recovery. The change in pasture management lead to changes in botanical composition from Stargrass to a native grass dominated pasture, in which *Paspalum* spp. and *Desmodium* spp. dominated among grasses and legumes, respectively.

Details of *A. pintoi* introduction into those pastures as well as initial pasture management were presented in previous chapters of this thesis. No fertiliser was applied after *A. pintoi* establishment. In June each year, the pastures were mechanically slashed down to a height of 10-15 cm to eliminate old growth from the previous year, to keep standing DM quality as high as possible.

The experiment started in 1998 with a 5 ha field (field 1) which was divided into 2 pastures of 2.5 ha each, one per treatment: native grass (NG) and NG associated with *A. pintoi* CIAT 17434 (NG+Ap). In 2000 another 5 ha field (field 2) was added to the study. This was also divided into 2 pastures of similar area, one per treatment. A fixed rotational grazing scheme of 1 day of grazing and 20 days of recovery was used. During the critical period of forage growth stocking rate was 2 cows/ha, while the remaining time the stocking rate was 3.2 cows/ha in order to consume the extra forage produced during the rainy season, which the permanent cows were unable to consume, and also to avoid old forage accumulation from reducing pasture quality. The extra cows were withdrawn from the trial whenever standing DM yield fell to 2500 kg/ha in any of the sampled paddocks, which generally occurred by the end of the year or beginning of the following. The milk yield and liveweight of the additional cows was not considered for statistical analysis since they were not *per se* measuring any response.

6. 2. 4 Statistical analyses

The response variables were: cow liveweight (LWC, kg/cow), saleable milk yield (SMY, kg of milk/lactation), calf liveweight (LWc, kg/calf) and accumulated calf milk intake (ACCMI, kg of milk/calf). The independent variables were treatment (T), and covariates, which will be mentioned later. The statistical analyses were done independently per year and field, because fields, having been established in different years, were not true replicates as to be used in a comprehensive analysis of variance.

All response variables, except SMY, were analysed by co-variance with a model that included the effects of T, the variation between animals within T to test the effect of treatments, the effect of the covariate, the interaction T by covariate and the residual variation as error term to test the effects of treatment and the interaction. The interaction T x by the linear effect of the covariate was significant in most of the years and for this reason, regression analysis was applied to estimate rates of gain and loss of weight of the animals.

The cow liveweight (LWC, kg/cow) was plotted against days from 1 January (D) in order to detect the peak LW attained. Then the data base was divided into two sets, one before and one after peak LWC was attained, peak value being included in both. A linear regression of LWC on D was fitted for each treatment by year combination on each field. In the before peak regressions, the intercept was an estimate of LWC on 1 January and the slope was an estimate of average daily gain (ADG, kg/cow/day). In the after peak regression, the intercept estimate had no biological meaning, but the slope estimated of the average daily weight loss (DWL, kg/cow/day). The intersecting point of before and after peak regression lines represented the peak LWC. The days to reach peak LWC were estimated graphically. Slopes (ADG, DWL) were compared with a 't' test.

The mean LWC changes were fitted into a log-normal equation:

$$Y = Y' + a*e^{(-0.5(nl(X/X')/b)^2)}$$

in which, Y is LWC at time X, 'Y'' is the baseline LWC, 'Y' + a' is the peak LWC, 'e' is the base of the natural logarithm, 'nl' is the natural logarithm which gives the curve its skewed peak, 'X' is the day after 1 January, 'X'' is the number of days to reach peak LWC, 'b' is a rate constant which indicates the amplitude of the "mountain" at its base *i. e.* the larger its value, the more time to reach peak liveweight and baseline liveweight after peak weight. The factor '-0.5' and the exponent '2', give the curve the bell shape. The Sigma Plot© Version 4.0 software was used to fit the equation to the data (SPSS, 1997).

A linear regression of LWc on age of the calf (A) was performed per each T x Y combination, in which the intercept was an estimate of the birth weight of the calf, and the slope was an estimate of its average daily gain (ADGc, kg/calf/day). Treatment slopes were compared within each year with a 't' test.

The scatter plot of daily milk intake against age of calf did not show any trend, and the mean daily milk intake had a high standard error. Thus the daily milk intake was multiplied by the days between two consecutive measurements, which gave the total milk intake in that period. This was added to the previous value of accumulated milk intake, and so on. Thus each age value had a correspondent accumulated milk intake (ACCMI, kg/calf). When both variables were regressed it gave a smooth linear response with a slope which would be an estimate of average daily milk intake (DMI, kg/calf/day) with the advantage of having a lower standard error. Again, treatment slopes were compared within each year with a 't' test.

Saleable milk yield (SMY, kg/cow/lactation) was analysed with a model that had the effects of T, Y and their interaction; covariates also included in the model were number of lactation, days in lactation and SMY in the previous lactation.

Statistical analyses were performed with the PROC GLM (generalised linear models) procedure of the Statistical Analysis System, as suggested by Littel *et al*. (1991).

6. 3 Results

6. 3. 1 Cow liveweight

6. 3. 1. 1 Before peak LW

In field 1, the ADG in 1999 favoured NG over NG+Ap, but the contrary occurred in 2000. In 1998 and 2001 treatments behaved similarly (Table 1). In field 2, cows in NG gained more than those in NG+Ap, which did not gain weight, but in 2001 ADG was the same for both treatments (Table 6. 1).

Table 6. 1. Treatment comparison for average daily gain (ADG, kg/cow/day) before peak LWC, daily weight loss (DWL, kg/cow/day) after peak LWC, and calculated peak LWC and days to reach peak LWC, for all combinations between fields and years.

Year	ADG		P[1]	DWL		P[1]	Peak LWC		Days to Peak	
	NG	NG+Ap		NG	NG+Ap		NG	NG+Ap	NG	NG+Ap
Field 1										
1998	0.772 ± 0.194	0.759 ± 0.087	0.8899	-0.426 ± 0.157	-0.137 ± 0.098	0.0026	562	523	134	77
1999	0.635 ± 0.277	0.140 ± 0.229	0.0001	-0.038 ± 0.101	-0.020 ± 0.043	0.1546	510	498	81	29
2000	0.191 ± 0.113	0.807 ± 0.165	0.0001	-0.303 ± 0.185	-0.513 ± 0.116	0.2039	499	586	160	126
2001	0.869 ± 0.161	0.601 ± 0.230	0.2969	-0.580 ± 0.176	-0.321 ± 0.099	0.0158	564	584	139	115
Field 2										
2000	0.306 ± 0.089	-0.007 ± 0.219	0.0011	-0.263 ± 0.088	-0.352 ± 0.158	0.0228	523	509	110	289
2001	0.705 ± 0.265	0.751 ± 0.278	0.2441	-0.091 ± 0.094	-0.132 ± 0.109	0.6398	505	524	63	58

1. Probability of the comparison between treatments.

6. 3. 1. 2 After peak LW

In field 1, the cows in the NG treatment lost weight at a rate 3 times faster than that shown by the NG+Ap treatment in 1998. A similar pattern was observed in 2001, but the DWL for NG was 1.8 times faster (Table 6. 1). In field 2, the cows in the NG+Ap lost weight 1.5 times faster than those cows on NG in 2000 (Table 6. 1).

6. 3. 1. 3 LWC description by the log-normal equation

The fit of the log-normal equation to the mean LWC was acceptable. In all years and treatments the model was highly significant ($P<0.01$) or significant ($P<0.03$). The lowest R^2 values were for 1999, while in other years these ranged from 0.67 to 0.94. The peak LW parameter component ‘a’ was negative for the NG+Ap treatment in 1999, so in that year, the LWC of the cows showed a nadir instead of a peak. All other ‘a’ values were positive (Table 6. 2 and Figure 6. 1). Peak LWC values calculated from this model were less variable than the times to reach the peak (Figure 6. 1).

6. 3. 2 Calf liveweight and milk intake

6. 3. 2. 1 Liveweight

There was not a consistent superiority of one treatment over the other from one year to the other with respect to ADG. Very small differences of around 0.05 kg/calf/day were highly significant, mainly due the high number of degrees of freedom (>120) to perform the 't' test (Table 6. 3). In field 2, the behaviour was similar: in 2000 NG calves gained more than those in NG+Ap, but the contrary occurred in 2001 (Table 6. 3).

Table 6. 2. Parameters of the log normal function adjusted to treatment liveweight means in each year from 1998 to 2001.

Year	Treatment	Number of means[1]	Function parameters						P>F
			Y'	a	X'	b	R^2	RSD	
1998	NG	12	471.1	102.6	147.6	0.3948	0.90	± 12.0	0.0001
	NG+Ap	12	478.8	62.2	119.4	0.4953	0.93	± 5.7	0.0001
1999	NG	12	455.5	59.2	134.2	1.0961	0.34	± 12.6	0.0204
	NG+Ap	12	493.2	-30.1	197.5	0.1461	0.37	± 10.7	0.0213
2000	NG	11	482.0	33.9	127.5	0.3082	0.67	± 8.1	0.0126
	NG+Ap	11	494.3	79.1	129.4	0.3487	0.94	± 7.3	0.0001
2001	NG	10	467.0	62.6	122.2	0.5227	0.87	± 8.5	0.0012
	NG+Ap	10	516.9	48.4	90.6	0.2864	0.89	± 5.8	0.0009

1. The number of observations (cows) per mean varied with the year. In 1998 and 1999, each mean was obtained with 5 observations. In 2000 and 2001, there were 10 observations per mean.

6. 3. 2. 2 Milk intake

In field 1 the DMI was different between NG and NG+Ap treatments only in 1998, while in field 2 both treatments differed, DMI being higher in NG in 2000 and lower in 2001. Apparent milk conversion rates were very similar among treatments in each year (Table 6. 3). The AMCR was in appearance more efficient in 2001, because milk intake decreased as a result of the calves suckling only once a day.

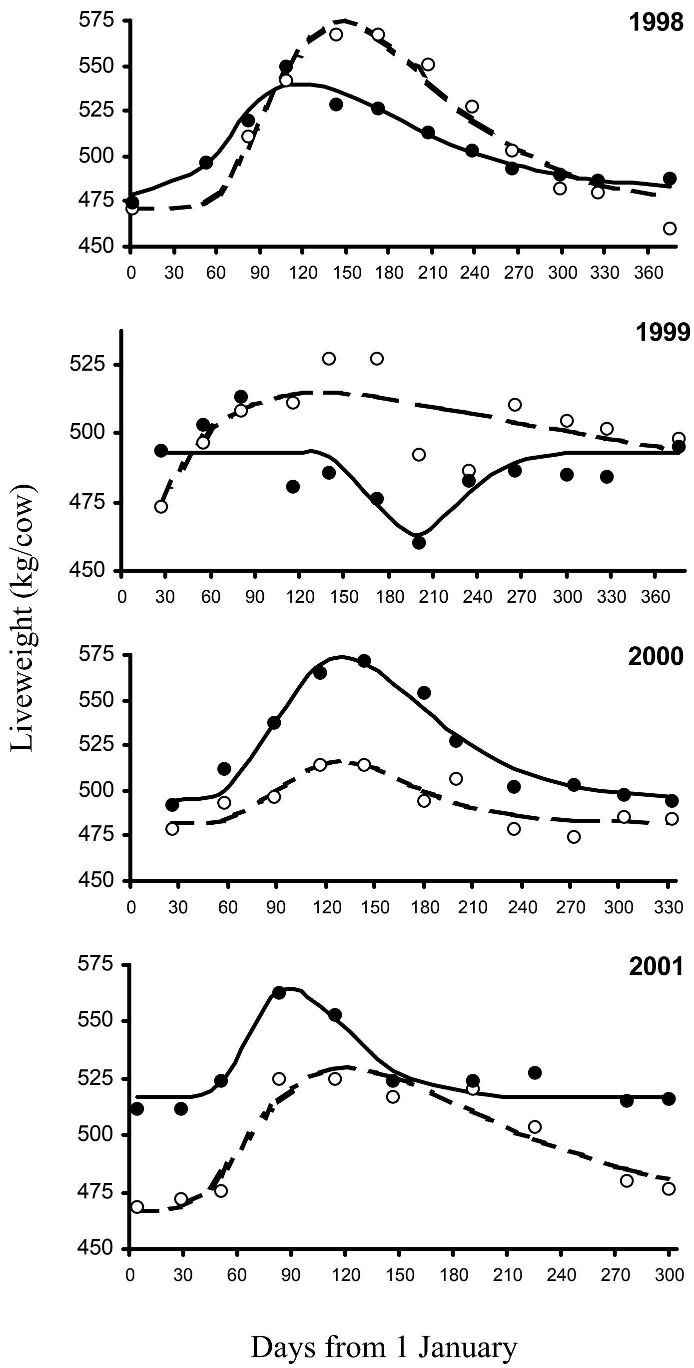

Figure 6. 1. Cow liveweight change with time from January 1998 to October 2001, of F1 (Holstein x Zebu) dual-purpose cows that grazed native grass (NG: open dot, broken line) pastures or NG associated to *Arachis pintoi CIAT* 17434 (NG+Ap: black dot, continuous line). Log normal model parameters are shown in Table 3.

Table 6. 3. Treatment comparisons for average daily gain of the calf (ADGc, kg/calf/day), daily milk intake (DMI, kg/calf/day), and calculated apparent milk conversion rate (AMCR = DMI/ADG), for all combinations between fields and years.

Year	ADGc		P^1	DMI		P^1	AMCR	
	NG	NG+Ap		NG	NG+Ap		NG	NG+Ap
				Field 1				
1998	0.594 ± 0.038	0.513 ± 0.040	0.0001	4.232 ± 0.321	3.607 ± 0.302	0.0001	7.1	7.0
1999	0.704 ± 0.036	0.740 ± 0.021	0.0055	4.708 ± 0.215	4.575 ± 0.167	0.1143	6.7	6.2
2000	0.564 ± 0.041	0.567 ± 0.026	0.4155	3.957 ± 0.286	3.916 ± 0.172	0.3550	7.0	6.9
2001	0.568 ± 0.033	0.543 ± 0.026	0.0012	2.146 ± 0.102	2.056 ± 0.139	0.2073	3.8	3.8
				Field 2				
2000	0.518 ± 0.054	0.450 ± 0.037	0.0003	4.491 ± 0.489	3.432 ± 0.325	0.0001	8.7	7.6
2001	0.544 ± 0.021	0.587 ± 0.029	0.0124	2.098 ± 0.071	2.475 ± 0.144	0.0102	3.9	4.2

1. Probability of the comparison between treatments.

6. 3. 3 Milk yield

In field 1 the difference in SMY was significantly higher in NG+Ap as compared to NG in 1999; no differences between treatments were detected in other years. In field 2 there were no treatment differences in any year (Table 6. 4).

6. 4 Discussion

6. 4. 1 Cow liveweight

The ADG of the cows before peak LW was due to the development of the foetus, which is particularly fast in the last third of gestation, to which the accumulation of body energy reserves, generally as fat, are added. On the other hand, the DWL after peak LW indicates body reserve mobilisation for milk production. In all, this can be considered the usual cycle of LW change of the cow from one parturition to the next.

Table 6. 4. Saleable milk yield per lactation (SMY, kg/cow), corrected for number of lactations, days in lactation and SMY in the previous lactation.

Year	Treatment		Significance
	NG	NG+Ap	
Field 1			
1998	1212 ± 102	1299 ± 98	0.5128
1999	1175 ± 96	1465 ± 98	0.0367
2000	1229 ± 99	1214 ± 93	0.9124
2001	1356 ± 98	1336 ± 101	0.8797
Field 2			
2000	1579 ± 87	1671 ± 82	0.4632
2001	1402 ± 89	1571 ± 78	0.1866

The peak liveweight, estimated by the intersection of the two lines, was an approximation of the weight of the cow at calving. The days taken to reach peak LW indicated that the cows entered the experiment at different stages of gestation. This questions the validity of comparing the ADG of cows with different times to calving after entering the study, first, because of the differences in foetus development and second, because the cows were exposed to a new diet at a different physiological stage and this could lead to differences in body reserve accumulation not due to treatments, but to stage of pregnancy. This factor was not considered when choosing the cows for the experiment, since the attention was centred on balancing for previous saleable milk yield and number of lactation.

Studies with Holstein cows, showed that about 11% to 13% of lactation milk yield is dependent on accumulated reserves (Wood, 1977). If this does or does not lead to an effect on milk production in the present study is the subject of conjecture, but both in 1998 and 1999, the cows in NG+Ap showed a shorter time to reach peak LW, a lower peak LW than the cows on NG, and also lower DWL. In both years saleable milk yields were higher in NG+Ap than in NG. However, this trend was not consistent in the remaining years and fields, so as to justify correcting the milk yield for ADG or DWL, of the cow.

The deposition of body reserves contributes to weight gain previous to parturition. Such reserves are visually estimated by scoring the body condition of the cow (Wettemann, 1994). A body condition score (BCS) at calving of 2.5 to 3.0, in an scale of 1, too thin to 5, too fat, is deemed necessary to assure pregnancy. In the present study, BCS was not evaluated, but must have been very similar among cows, since pregnancy rates were similar ($P<0.7534$) between treatments. Pregnant/exposed cows for 1998 to 2001 for NG were 24/30 and 23/30 for NG+Ap. The average pregnancy rate of 80% is far superior to that of commercial herds, which is around 50% (Corro *et al*., 1999). If conventional wisdom about reproductive performance being the best indicator of the cow's nutrition is accepted (Wettemann, 1994), then, for reproductive purposes, NG pastures provided the cows with a nutrition as good as that given by the NG+Ap pastures.

In the treatment NG+Ap 1999 in field 1, the peak LWC occurred very early (29 days) and subsequent DWL, while being slightly negative, was not different from zero. In NG+Ap 2000 in field 2 a peak LWC was not detected because on the average the cows lost weight from the beginning of the year. The interesting fact in both situations was that the animals pretty much kept a constant LWC throughout the year, and this may have been due to having been offered DM of a higher quality by the NG+Ap pasture. This is supported by the fact that in both cases SMY was also higher than that of the corresponding NG pastures.

The representation of the performance of any character associated with production using a single algebraic expression is of practical importance, because it is possible to predict the LWC changes during the production cycle that bear a direct effect on the DM intake from pasture (Menchaca and Ruiz, 1987; Wood, 1977), and from there, an annual feeding plan for the herd can be developed.

The peak LWC values were of a different magnitude each year, as in most cases were the days to reach peak LWC, something coincident in form but not in magnitude, with the simple linear regressions before and after peak LWC. The reason being that in the former the log-normal model was fitted to averages and in the latter the linear regression model was fitted to individual cow observations. This also contributed to the smooth response described by the peak model.

A fast approach to peak LWC and a fast decline after it was associated with low ‘b’ values. Therefore, the design of a feeding plan for these type of cows, must focus on producing LWC curves with ‘b’ values of medium magnitude i. e. 0.3 to 0.5, since these indicate that the manager is preventing the cow from loosing too much weight before the critical winter period. In the present case, the model indicated that the cows that grazed NG+Ap lost LWC at a lower rate than those in NG only in 1998. In the remaining years, the cows in NG were better in this respect. Also, the fitting of the log-normal model to the data served the purpose of showing the year dependence and not the treatment dependence of the LWC during the year, which supported in general the trends shown by the linear regression equations.

6. 4. 2 Calf liveweight and milk intake

Restricted suckling is the best way of rearing calves in tropical dual-purpose systems, while at the same time keeping saleable milk yields relatively high (Ryle and Orskov, 1990; Ugarte, 1991). Many restricted suckling modalities have been studied over time and across the tropics of the world, nevertheless, there are few reports, if any, of the effect of pasture type on performance of restricted suckling calves, particularly when one of the treatments is a legume-based pasture.

The ADG shown through the years by calves of both treatments can be considered high for restricted-suckled calves, particularly that of 1999. However the ADG values were around 0.55 kg/calf/day in the remaining years, even in 2001, when calves suckled once daily. In Tanzania Sanh *et al*. (1995) found in one experiment that calves of Boran, Friesian and Ayrshire breeds that suckled two times a day and weaned at 6 months of age, gained on the average 0.45 kg/calf/day with an apparent milk conversion of 3.9 kg of milk/kg of ADG. In another experiment Sanh *et al*. (1997) used F1 (Friesian x Local) cows in Vietnam and found that calves under restricted suckling 2 times a day gained 0.44 kg/calf/day with an apparent milk conversion of 4.2 kg/kg of ADG. In both experiments the calves were provided with 200 kg of concentrate given in increasing amounts in 6 months, about 1.1 kg/calf/day, pretty much the same amount given in the present study. In our experiment, calves suckled once daily in 2001, but in spite of having a reduced milk intake as compared to previous years, the ADG was above 0.5 kg/calf/day in both fields.

Milk composition, particularly fat and non-fatty solids, determine the amount of energy in milk which might be used for calf growth (Tyrrel and Reid, 1966). González *et al*. (1996) did not detect any difference in milk fat (3.1% in 1990 and 3.9% in 1991-1992) in cows grazing Stargrass or Stargrass associated with *A. pintoi*. Data from the present experiment for saleable milk in 1999 for the last 2/3 of the lactations of the cows in field 1, failed to show significant differences (P=0.1205) between treatments in concentrations of milk fat (4.8%), but those of total solids were significantly higher (P=0.0165) for NG (13.3%) than for NG+Ap (12.5%) (Velasco, 2000). Mejía *et al*. (1998) found that the milk consumed by suckling calves was richer in fat than the milked milk (3.6% vs. 5.6%).

Holloway *et al*. (1982) showed that as the calf grew its nutrition depended less on milk and more on pasture, but calves that grazed fescue-legume pastures started earlier to depend more on pasture than on milk than those calves grazing fescue pastures, and this was due to the higher quality of the associated pasture. Also, the cows that grazed fescue-legume produced 0.4 kg/day more milk and weaned 24 kg more per calf than those cows grazing fescue.

There appeared not to be any differences between treatments in milk fat and total solids, the supplying of concentrate was standard, and calves grazed the Stargrass pastures in common. A differential intake of forage was unlikely since the Stargrass pasture always had ample DM availability, giving the animals the opportunity to select the highest quality plant material, to compensate any reduction of nutrients from milk and concentrate.

At the end, the calves of NG+Ap had no consistent advantage over NG, with respect to ADG and ACCMI. The significant differences in ADG between treatments within years can only be explained by the fact that the number of degrees of freedom to compare slopes was very high. A highly significant (P=0.0055) difference of only 0.036 kg/calf/day between NG and NG+Ap in 1999 would not have any practical implications for the future of the animal on the farm.

The reduction in DMI experienced by both treatments in 2001 was the result of reducing suckling from 2 times to once a day.

The AMCR values for the present experiment lie within a wide range of AMCR figures from literature reports from 4 to 20 (Sanh *et al*., 1995; Sanh *et al*., 1997; Mejía *et al*., 1998).

6. 4. 3 Milk yield

Total milk yield (TMY = SMY + DMI) in the present experiment falls within the category of young tropical pasture (Stobbs and Thompson, 1975). The lowest TMY was that of NG in 1998, which was 1726 kg per lactation, while the highest TMY was that of NG+Ap in 2000: 2090 kg of milk per lactation. Our pastures had a very short time of recovery of 20 days which produced plant material of high quality. Extrusa samples from NG and NG+Ap had an *in situ* digestibility of 72% and 74%, with respective CP values of 9.8% and 13.5%, indicating the advantages of having a *A. pintoi* included in the diet (Sosa *et al*., 2001).

Fernández-Baca *et al*. (1986) at the same experimental station from 1981 to 1983, found that a native grass pasture was the least productive as compared to those of introduced grasses, with milk yields of 2185 kg/ha in one year and 3514 kg/ha the next year. These values were obtained by milking the cows twice, and indicate that NG pastures can have a higher capacity for milk production than that found in the present study.

Lascano and Avila (1993) showed that Holstein cows responded better to a grass/legume association than did cross-bred cows. In Venezuela Vaccaro *et al*. (1995) conducted an on-farm study and found that dual purpose cows with a predominantly Zebu parentage and low level of European breed crosses (Z) were similar in milk yield per lactation as those with medium grade Zebu-European (M) or those high grade European plus pure European (H), when farm conditions allowed milk yields of 1000 kg per lactation or lower. However, when the level of feeding was improved the Z group produced less (2409 kg/lactation) than the M (2783 kg/lactation) and H (2757 kg/lactation) with no difference ($P>0.05$) between the latter two.

Thus, using cows of low production potential may render the beneficial effect of the legume, or an increased plane of nutrition, undetected. Animal management factors could have played a role in determining the reduced response to the better nutritional level provided by the NG+Ap treatment. The cows of the present study were milked once daily and gave about 6 kg of milk/cow/day. In the same experimental station, similar cows yielded about 7.5 kg/cow/day when they were milked twice daily (Acosta *et al*., 1997). Had our cows been milked twice, this would have created an immediate higher demand for nutrients because of a higher milk yield, giving a chance to the association to express its potential for a higher milk production.

The short breeding season aimed to obtain a calf per cow each year requires a weaning age of 4 months. The absence of the suckling calf shortens lactation length, particularly when the cow has >50% of Zebu parentage (Vaccaro *et al*., 1999). In the present case, lactation lengths were shorter than those reported by Corro *et al*. (1999) for farms with year-round calving in the same region. So, it is probable that the seasonal calving plan may be interacting with the type of cattle, to reduce lactation length and as consequence to divert nutrients for weight deposition instead of milk production.

The literature supports well the expected benefits that can be obtained by using legumes in association with grasses or as complementary grazing on milk yield (Davison and Cowan, 1978; Saucedo *et al*., 1980; Lascano and Avila, 1993).

In the piedmont zone of Caquetá, Colombia, Ullrich *et al*. (1994) found positive effects of associating *Brachiaria decumbens* with a mixture of legumes in which *A. pintoi* was included. The relevance of this study was that it was conducted on-farm. The best response was observed during the dry season, since in 6 out of 10 farms the difference in SMY favoured ($P<0.05$) the association. The response to the association was present only in 3 farms during the rainy season. Therefore, in a region with a prolonged growing season like the one in our study, a clear cut difference in favour of the association may be more difficult to detect.

In Costa Rica, González *et al*. (1996) associated Stargrass (*Cynodon nlemfuensis*) with *A. pintoi* and had Jersey (J), Criollo Lechero (C) and L x C crosses, grazing both types of pastures. In 1990, the associated pasture yielded 7.7 and the Stargrass pasture 8.8 kg/cow/day, a difference of 14%. In a second cycle of production in 1991-1992, the milk yield per cow was higher, but the relative difference between treatments was similar: 9.5 *vs*. 10.8 kg/cow/day, 13.7%. This difference was associated with a higher nutritive value of the association.

In the present study, the average difference for SMY in favour of the association was 7.3% in field 1 and 8.9% in field 2. It was noticeable that the difference between pasture treatments diminished with time in field 1. Even though this was apparently related to a decline in standing DM in the association (Chapter 4 of this thesis), this could not have played an important role in determining the SMY, since DM on offer was above 10 kg DM/100 kg LWC most of times in both treatments, which assured an availability of about 50 kg DM/cow, plenty of forage for the animal to reach its maximum pasture intake (Combellas and Hodgson, 1979; Le Du *et al*., 1979).

The introduction of *A. pintoi* into commercial and traditionally managed pastures usually increases animal performance, and that may lead to a profitable income for the farmer. This was suggested by the positive results obtained by Jansen *et al*. (1997) in Costa Rica for *Brachiaria brizantha*/*A. pintoi* pastures.

6. 5 Conclusions

1. From an exclusive medium term animal production perspective, there appears to be no advantage of introducing *A. pintoi* into an adequately managed native grass pasture.
2. Animal performance must be the main immediate concern when a legume is introduced into a native grass pasture, but positive changes in other components of the pasture agro-ecosystem must not be overlooked, like soil fertility improvement and C sequestration in the soil.

7

SHORT TERM PASTURE INTAKE AND INGESTIVE BEHAVIOUR OF DUAL-PURPOSE COWS ON A NATIVE GRASS/*Arachis pintoi* PASTURE IN THE HUMID TROPICS OF MÉXICO

7. SHORT TERM PASTURE INTAKE AND INGESTIVE BEHAVIOUR OF DUAL-PURPOSE COWS ON A NATIVE GRASS/*Arachis pintoi* PASTURE IN THE HUMID TROPICS OF MÉXICO

7. 1 Introduction

Studies with beef cattle grazing subtropical grass and grass/legume mixtures in seasonally dry subtropical Queensland, Australia, showed an asymptotic response of liveweight gain to green-DM on offer. Compared to the grass component, the legume approached the asymptotic live weight gain at lower levels of pasture offer, because gain was higher for the legume than for the grass at similar levels of offer, indicating a nutritional advantage of the legume over the grass, but more than 30% of legume in the green-DM on offer did not benefit cattle performance in that study (Mannetje, 1974). At maximum gain per animal, DM intake should also be maximum and individual performance will depend on the concentration of nutrients in the pasture. Thus, DM intake and quality of ingested DM are necessary measurements to explain differences in animal production from different pasture treatments (Minson, 1990).

The grazing ruminant uses sight, taste, smell and touch to select the patch of pasture to be eaten (Wade and Carvalho, 2000). Pasture management manipulates the quantity and botanical composition of the herbage on offer to obtain the highest animal performance. Changes in sward characteristics would induce changes in the usual grazing pattern of the animal and may affect the amount and quality of eaten forage. Then, it is advisable to describe the ingestive behaviour of the animal as it is affected by pasture management (Hodgson, 1982).

Previous studies on DM intake and quality, and related ingestive behaviour of ruminants grazing *A. pintoi*-based pastures, have been conducted with sown introduced grasses as companion species, and mostly with beef cattle (Carulla *et al*., 1991; Hernández *et al*., 1995; Hess *et al*., 2002).

Thus, the objective of the study presented in this chapter was to determine the effect of introducing *A. pintoi* into a native grass pasture on organic matter (OM) intake, digestibility of OM, and crude protein (CP) content of the ingested herbage and on ingestive behaviour of dual-purpose F1 (Holstein x Zebu) cows that grazed a native pasture of the humid tropics of central State of Veracruz, México.

7. 2 Materials and methods

7. 2. 1 Site

The experiment was carried out in July and August, 2001. The geographical situation of the experimental site as well as its climate and soils were described in previous chapters. Minimum and maximum air temperatures under shade, rainfall and relative humidity were recorded daily between 7:00 and 10:00 AM during the experimental period.

7. 2. 2 Treatments

The experiment had two treatments: The native grass pasture (NG) and NG into which *Arachis pintoi* (CIAT 17434) was introduced (NG+Ap) (See 2.4). Each treatment occupied a 2.5 ha of pasture.

7. 2. 3 Animal management

7. 2. 3. 1 Intact cows, and calves

The management of cows and calves was described in chapter 6 of this thesis. The cows in this experiment calved between April and June, 2001 and they were between the 3rd and 6th lactation. At the beginning of the trial their average body condition score was 2.0 ±1.0.

The cows were machine milked once a day at 8:00 AM from week two after calving. Saleable Milk Yield (SMY) per cow (kg/cow/day) was recorded daily from the measurement cuvettes of the milking system. The cows were supplemented with sugarcane molasses during milking time at about 1 kg of DM per cow per day.

The unfasted weight of the cows was registered on the last Friday of each month or the first Friday of the next month, in the morning, after milking and suckling if in lactation. The June, July and August live weights were used to calculate the individual weights of the cows for the experimental period.

7. 2. 3. 2 Fistulated animals

There were 2 oesophageally fistulated (OF) cows, each fitted with a 4 cm diameter permanent cannula. These animals were used to sample the pastures to be offered to the intact cows. To prevent health problems cannulae and fistulae were thoroughly checked and cleaned every sampling day. Cows sampled two days, one day per treatment, and rested one day, until a complete 21 day grazing cycle was completed. The OF cow liveweight was similar to that of the resident cows of the experiment.

Three bulls with a ruminal fistula and fitted with a 10 cm diameter permanent cannula were used to estimate the *in situ* digestibility (ISD) of the oesophageal extrusa samples obtained with the OF cows, as well as the ISD of the standing DM. These animals were used to handling for *in situ* measurements. To assure an active population of rumen micro-organisms, the bulls received about 3 kg per head per day of a 14% CP, 2.4 MJ of ME/kg DM concentrate, 5 days before the start of a series of ISD runs and while in use for the same purpose. The animals were European x Zebu crosses, about 5 years old and weighed around 700 kg.

7. 2. 4 Pasture management

Details of *A. pintoi* introduction into those pastures and of initial pasture management were given in chapters 3 and 6 of this thesis.

The field phase of this experiment took place from July 29 to August 19 of 2001. Each pasture had seven divisions and each division was subdivided into three paddocks each of 1190.5 m^2, which gave 21 paddocks per pasture treatment, each grazed for 1 day and allowed to recover for 20 days. Five fixed cows per 2.5 ha pasture were used (stocking rate of 2 cows/ha). The cows were turned into a new paddock every day, in the morning, just after milking, and remained there until next morning, when they were taken out to be milked again.

7. 2. 5 Pasture measurements and forage analyses

Each day of the 21-day grazing cycle, the standing DM (SDM, kg DM/ha) and the botanical composition (BC, percent contribution per component) of the pasture were estimated. Both measurements were done in the late afternoon, previous to the day that the cows entered a new paddock. The SDM was determined with the comparative yield method (CYM) (Haydock and Shaw, 1975).

The BC was estimated with the dry weight rank method (DWR) (Mannetje and Haydock, 1963), which was applied simultaneously with CYM on the same 100 quadrats. Eight species or groups of species were considered: *A. pintoi* (AP), native legumes (NL), introduced grasses (IG), native grasses (NG), Bitter grass (BG), Savanna grass (SG), broad-leafed weeds (BW) and narrow-leafed weeds (NW). The main species composing the botanical groups were mentioned in chapter 4 of this thesis.

The forage from the five standard quadrats cut to estimate SDM by the comparative yield method, was weighed and dried at 65 °C/72 h and ground in a Wiley mill with a 1 mm sieve. A sample for analyses was composed in accordance to the relative SDM of each individual quadrat. Analyses were done in duplicate for ash (ASH, % of DM) using a muffle furnace at 550°C for 8 h, CP (N x 6.25) with a macro Kjeldahl method, and *in situ* organic matter digestibility (ISOMD) (Mehrez and Ørskov, 1977; Ørskov and Mc Donald, 1979) in triplicate within each rumen-fistulated bull.

On the same day, about four hundred hand-plucked samples were obtained from the paddock, imitating as closely as possible that apparently grazed by the cows. A 1 kg sample of the mixed fresh material was dried at 65 °C/72 h and ground in a Wiley mill with a 1 mm sieve. The ground material was analysed for ASH, CP and ISOMD, as described above. Only one operator took the hand plucked samples.

7. 2. 6 Measurements on oesophageal extrusa

The two OF cows were left overnight without feed but with water available. Early in the morning the caps on the fistulae were removed and the cows fitted with collection bags, directly below the fistula, and attached to a halter. They were taken to the experimental paddock that was to be grazed by the intact cows that day, and allowed to graze at around 8:00 AM. The collection time was 30 minutes, or shorter if the collection bags had been filled, during which the number of bites was also counted. The procedure was repeated at about 6:00 PM. The NG+Ap treatment was always sampled first and the next day the NG treatment was sampled. Within the 21 day grazing cycle, each pasture was sampled 7 times in the morning and 7 times in the afternoon.

The excess liquid and saliva in the oesophageal extrusa was eliminated by gently pressing cheesecloth against the fresh mass. After that, it was divided into 3 sub-samples: 1) 200 g were used for DM, CP, ASH and acid insoluble ash (AIA) determinations, 2) 400 g were frozen (-20 °C) to be used later for *in situ* digestibility measurements, and 3) 400 g for botanical composition estimation.

7. 2. 6. 1 Nutritive value of oesophageal extrusa

DM, CP and ASH of oesophageal extrusa were analysed as described. For ISOMD (% of DM) measurements, the frozen oesophageal extrusa was thawed at room temperature and approximately 20 g of the thawed material was placed in a 10 cm x 20 cm nylon bag. Three bags per treatment (2) x cow (2) x day (7) x time of day (2) combination were used. The bags were placed in a nylon net fabric sac, and placed in each of the 3 rumen-fistulated bulls. Rumen incubation time was 48 h. Duplicate samples from the thawed material were analysed for DM, CP and ASH.

7. 2. 6. 2 Botanical composition of oesophageal extrusa

The botanical components were: *A. pintoi* (Ap), native legumes (NL), grasses (GR) and other species (OS). The 400 g sub-sample was spread as evenly as possible on a tray and examined under the stereoscopic microscope. The botanical composition of the oesophageal extrusa was calculated over 400 observed points. This is a variation of the technique proposed by Harker *et al*. (1964), for the microscopic evaluation of the botanical composition of extrusa.

7. 2. 7 Ingestive behaviour

Ingestive behaviour measurements followed the techniques described by Hodgson (1982). All measurements relied on direct observation, either looking at or listening to the grazing activities of the cows.

7. 2. 7. 1 Grazing time, ruminating time and other activities

The activity of the intact cows on pasture was classified into: Grazing (GT), when the animal was observed with her head down close to the sward and either biting or approaching to bite a patch of pasture; ruminating (RT), when the animals were chewing the cud either standing up or lying down; and other activities (OA), if the animal was neither grazing nor ruminating, but standing up, laying down or walking. These variables were registered for each animal by the interval sampling technique, observing activities at 10 minutes intervals for 24 hours, starting at 10:00 PM and ending at the same time the next day. To calculate the time spent on each activity, it was assumed that each record represented the activity over the time interval since the previous record. Each animal was observed for about 10 seconds. These measurements were expressed in minutes per 24 hours.

7. 2. 7. 2 Biting rates

Biting rates were estimated using intact cows (BR_{IC}, bites/minute) as follows: On the last 10 minutes of each hour, and if the cow was grazing, the time spent on applying 20 uninterrupted bites was registered for each cow.

Biting rates were also determined in oesophageally fistulated cows (BR_{OF}, bites/minute). The two OF cows were allowed to graze for a maximum of 30 minutes; in this time the number of bites applied during the effective grazing time (grazing time within the allowed sampling time) was counted. Then, BR_{OF} was equal to the number of bites divided by the effective grazing time.

In both BR_{IC} and BR_{OF}, the criteria to define bite was the characteristic sound produced when the pasture was severed by the cow, which was easily audible (Chilibroste *et al*., 1997).

7. 2. 7. 3 Bite size

Bite size of intact cows (BS_{IC}, g OM/bite) was calculated by taking the daily OM intake (kg OM/cow/day), estimated from the double-marker method (Cr-AIA), and dividing it by the daily number of bites (bites/day = GT x BR_{IC}).

The bite size of oesophageally fistulated cows (BS_{OF}, g OM/bite) was calculated as the collected OM mass of oesophageal extrusa divided by the total number of bites, both recorded during the effective grazing time.

7. 2. 8 Pasture intake

7. 2. 8. 1 Double marker technique (Cr-AIA)

Chromium sesquioxide (Cr_2O_3) was used as an external marker to estimate the daily output of faeces. The compound used was industrial-grade, with a slightly variable Cr content of 68.51% ± 0.21% (CV=0.31%; n=36), which was chosen because of its low price and the acceptable results obtained in various grazing trials carried out in the Mexican tropics

(Mendoza[*]). The intact cows were dosed daily for 19 days with 4.0 grams of the marker. It was assumed that the first 12 days were necessary to achieve the steady state flow of the marker. On the last 7 days, faeces were collected individually, either from faeces recently dropped in the field, or directly from the rectum. A sample for analysis was composed from daily aliquots. Cr content was determined with atomic absorption spectroscopy (Le Du and Penning, 1982). The production of faeces was obtained with the formula:

Faeces production = Amount of Cr dosed / Concentration of Cr in faeces

Acid insoluble ash (AIA) (Van Keulen and Young, 1977) was used as an internal marker to estimate the DM digestibility of the pasture consumed by the cows. AIA was determined from the same faeces sample used for Cr determination, and also in the oesophageal extrusa. Therefore, the digestibility was:

Digestibility = Concentration of AIA in extrusa / Concentration of AIA in faeces

The organic matter intake (OMI, kg/cow/day) was calculated as follows (Le Du and Penning, 1982):

OMI = Faeces production (g OM/cow/day) /1 - OM Digestibility

7. 2. 8. 2 Single marker technique (Cr-ISOMD)

In this case, faecal excretion was the same as mentioned above, and the *in situ* OM digestibility values were those of the extrusa samples. The intake formula remained the same.

7. 2. 8. 3 Ingestive behaviour technique

Intake was calculated as the product of bite size by biting rate by grazing time (Hodgson, 1982). Bite size was that obtained with the OF cows (BS_{OF}), and BR and GT were obtained with the intact cows (BR_{IC} and GT_{IC}, respectively).

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[*] Personal communication. Germán Mendoza Martínez, Ph. D., Profesor Investigador, Especialidad de Ganadería, Instituto de Recursos Genéticos y Productividad, Colegio de Postgraduados, Montecillo, Edo. de Méx., México.

7. 2. 9 Statistical analyses

7. 2. 9. 1 Experimental design

This experiment did not have field replication for treatments since a single pasture of each treatment was used. Therefore, for the response variables measured on the pasture, the variation between paddocks was used to test the effects of treatments. For the grazing behaviour variables and other variables measured on the animals, the variation between cows was used to test the effects of treatments. The effects of time (day of sampling or time of the day) and their interactions with treatment were tested against the residual variation.

7. 2. 9. 2 Response variables

The following response variables were either measured or calculated: 1) Standing DM before grazing (SDM, kg/ha) and its DM content (% of fresh weight); 2) Botanical composition of the pasture before grazing (%); 3) CP (%) and *in situ* OMD (ISOMD, %) of the SDM; 4) DM, CP, and ISOMD of hand plucked herbage; 5) DM, CP, ISOMD, and botanical composition (component, %) of oesophageal extrusa; 6) Grazing time (GT, minutes/24 h), ruminating time (RT, minutes/24 h), and other activities time (OT, minute/24 h) of intact cows; 7) Bite rate of oesophageally fistulated (BR_{OF}, bites/minute) and intact (BR_{IC}, bites/minute) cows; 8) Bite size from oesophageally fistulated (BS_{OF}, g OM/bite) and intact (BS_{IC}, g OM/bite) cows; 9) OMD by the AIA method; and 10) OMI on liveweight basis (OMI_{LW}, kg/100 kg of liveweight) and on metabolic weight basis (OMI_{MW}, g OM/kg $LW^{0.75}$).

7. 2. 9. 3 Analyses of variance

The analyses of variance were performed with the PROC GLM (generalised linear models) procedure of the Statistical Analysis System, as suggested by Littel *et al*. (1991).

7. 3 Results

7. 3. 1 Standing dry matter

The DM content of the NG+Ap pasture was lower than that of the NG both in the whole sward and the hand plucked herbage by about 4 percent units in either case, but only in the former the difference was significant (Table 7.1). The CP content of the NG+Ap pasture was higher than that of the NG pasture by a factor of 1.5 in the whole sward and 1.6 in the hand plucked herbage, but the content of CP of the latter was superior to that of the whole sward. The ISOMD showed a trend similar to that of the CP (Table 7. 1). Differences in botanical composition between treatments were only due to *A. pintoi* and native grasses. The results were reversed with respect to the NG treatment in which the native grass species contributed almost 69% to herbage DM, while in the NG+Ap pasture this was only 28%. The other species or botanical groups did not differ among both pastures (Table 7. 1).

7. 3. 2 Oesophageal extrusa

The extrusa DM content was significantly higher for the NG pasture, but on the contrary, its CP and ISOMD contents were significantly lower than those of the NG+Ap treatment. Only *A. pintoi* and grasses contributed significantly to the botanical composition of the extrusa, the other components contributing much less to the animal's diet so as to be of biological importance (Table 7.2). The CP in extrusa increased one percent unit per each 8.7 percent units *A. pintoi* increased in the botanical composition of the same extrusa (Figure 7. 1).

7. 3. 3 Grazing behaviour

The cows on the NG sward grazed longer than those on the NG+Ap association and they also ruminated for a longer time. The cows on the association spent more time with other activities than the cows in NG. In both treatments, the time spent daily by the cows out of the pasture was considerable: 265 minutes/day.

Table 7. 1. Characterization of the standing dry matter from native grass pastures (NG) and NG associated with *A. pintoi* CIAT 17434 (NG+Ap). Values are means ± standard errors.

Variable	Pasture		Significance of difference
	NG	NG+Ap	
Dry matter content (% of fresh weight)			
Whole sward	34.3±1.3	30.4±1.1	0.0106
Hand plucked herbage	28.5±2.0	24.2±2.7	0.1092
Standing dry matter (SDM, kg /ha)	2841±213	3449±275	0.1026
Crude protein (CP, % DM)			
Whole sward	7.9±0.1	11.9±0.2	0.0001
Hand plucked herbage	10.0±0.2	15.6±0.2	0.0001
***In situ* organic matter digestibility (ISOMD, % DM)**			
Whole sward	63.7±0.8	68.7±1.2	0.0013
Hand plucked herbage	71.2±0.3	79.6±0.4	0.0001
Botanical Composition (%)			
A. pintoi CIAT 17434 (Ap)	0.01±8.0	43.8±10.3	0.0189
Native legume (NL)	8.1±3.1	8.1±4.1	0.9989
Native grass (NG)	68.7±6.7	27.6±8.6	0.0131
Introduced grass (IG)	13.4±6.1	7.9±7.8	0.5369
Bitter grass (BG)	0.6±0.7	2.5±0.9	0.1413
Savanna grass (SG)	4.0±1.2	1.8±1.6	0.3566
Broad-leaved weeds (BW)	5.0±0.9	8.4±1.1	0.0708
Narrow-leaved weeds (NW)	0.2±0.1	0.02±0.1	0.2597

The intact cows on NG had a BR significantly higher by 24% than those on the associated pasture. In contrast, the BR of OF cows on both NG and NG+Ap had similar bite rates. The bite rate of the OF cows (29.0±1.0 bites/minute) was much lower than that of the intact cows (46±0.7 bites/minute). The bite size of the intact cows (BS_{IC}) was significantly larger in the association than in the NG pasture by a factor of 1.5. In the OF cows, the bite size was similar on both pastures. The BS values were much smaller for intact cows than for OF cows (Table 7. 3).

Table 7. 2. Characterisation of the oesophageal extrusa obtained from native grass pastures (NG) and NG associated with *A. pintoi* CIAT 17434 (NG+Ap). Values are means ± standard errors.

Variable	Pasture		Significance of difference
	NG	NG + Ap	
Dry matter content (% of fresh weight)	16.4±0.5	14.7±0.4	0.0064
Crude protein (CP, % DM)	10.9±0.4	14.8±1.0	0.0001
***In situ* organic matter digestibility (ISOMD, % DM)**	57.2±0.8	62.2±0.9	0.0001
Botanical Composition (%)			
A. pintoi CIAT 17434 (Ap)	0.01±0.01	38.1±5.2	0.0001
Grasses (GR)	99.5±0.10	61.6±5.1	0.0001
Native legume (NL)	0.5±0.1	0.2±0.1	0.0001
Other species (OS)	0.04±0.02	0.03±0.01	0.7083

7. 3. 4 Organic matter intake

Regardless of the technique used to estimate OMI, the intake on NG was higher than that on NG+Ap. Grazing behaviour resulted in an estimated intake twice as high as those obtained with the Cr-AIA or Cr-DIS techniques, which did not differ among them (Table 7. 4). Intake on a fresh matter basis was higher for the association regardless of the DM content considered for the calculation (Table 7. 5)

7. 3. 5 Animal performance

The cows on NG tended to yield more saleable milk than those on NG+Ap. The calf milk intake was significantly different between pastures, with a higher intake on the association, and a tendency for a higher calf daily gain. However, there was no difference in total milk yield (TMY) among pastures (Table 7. 6).

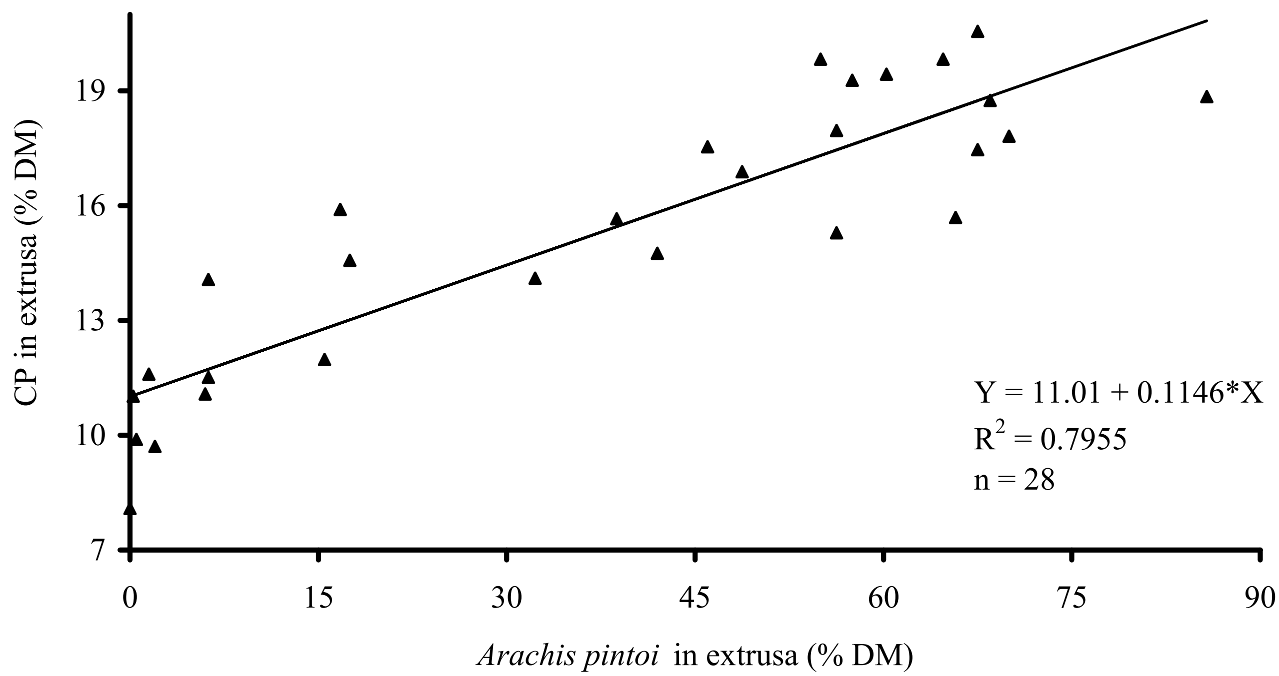

Figure 7. 1. The relationship between the percentage of crude protein (CP) in the extrusa and the contribution of *A. pintoi* to the extrusa's botanical composition.

7. 4 Discussion

7. 4. 1 Standing dry matter

The SDM has little value *per se* in a grazing study. It is more meaningful to express SDM as daily forage availability *e. g.* unit of forage on offer per unit of animal live weight, as in this form it can be related both to forage intake and to individual animal performance (Mott, 1960).

In tropical pastures the availability for maximum animal performance has been variable, from 5 up to 35 kg DM/100 kg LW. This ample range is due to differences in pasture type, quality and management between studies, which makes it difficult to apply the results of one experiment to a particular situation.

Table 7. 3. Ingestive behavior by F1 (Holstein x Zebu) cows grazing native grass pastures (NG) and NG associated with *A. pintoi* CIAT 17434 (NG+Ap). Values are means ± standard errors.

Variable	Pasture		Significance of difference
	NG	NG + Ap	
Intact cows			
Grazing time (GT, min/24 h)	457±13	395±11	0.0001
Ruminating time (RT, min/24 h)	406±14	376±14	0.0231
Other activities time (OA, min/24 h)	304±14	413±15	0.0001
Bite rate (BR_{IC}, bites/min)	51±0.75	41±0.72	0.0001
Bite size (BS_{IC}, g OM/bite)[1]	0.34±0.04	0.50±0.04	0.0001
Esophageally fistulated cows			
Bite rate (BR_{EF}, bites/min)	27±1	30±1	0.2175
Bite size (BS_{EF}, g OM/bite)	0.86±0.04	0.83±0.04	0.6461

1. Calculated from OM intake by the Cr-AIA technique, GT and BR. All measured in intact cows.

Since cattle eat mostly leaves and very little stem, it would be reasonable to express availability on green-DM basis as Mannetje (1974) did or better, in terms of leaf green-DM (Rogalski *et al*., 1990). In the case of the present experiment, the content of old senescent plant material was negligible, so availability, even though it was not expressed as such, was mostly green-DM. Also, in this study availability was above 12 kg SDM/100 kg of LW in either treatment, well within the wide range within which maximum animal performance is reached, and several times the OMI found in the present study.

In temperate pastures target forage utilisation rates vary between 33% and 50% (Combellas and Hodgson, 1979; Le Du *et al*., 1979). On a DM basis forage utilisation rates for the present study were 14.0% and 11.5% for NG and NG+Ap, respectively. In the same swards of the present trial, Monsalve *et al*. (2000) measured utilisation rates based on standing DM before and after grazing, of 11.4% and 13.6% for the same treatments. These values broadly agree with the literature that indicates low degrees of forage utilisation for tropical pastures, between 10% to 40% (Thomas, 1992).

Table 7. 4. Organic matter intake estimations by three techniques: Faecal excretion by chromium and indigestibility by acid insoluble ash (Cr-AIA), faecal excretion by chromium and indigestibility by *in situ* extrusa digestibility (Cr-ISD), and ingestive behavior measurements. Values are means ± standard errors.

Organic matter intake relative to:	Pasture		Significance of difference
	NG	NG + Ap	
Live weight (kg OM/100 kg LW)			
Cr - AIA	1.49±0.10	1.46±0.04	0.0001
Cr - ISD	1.50±0.10	1.43±0.03	0.0001
Grazing behavior	3.72±0.42	2.40±0.26	0.0001
Metabolic weight (g OM/kg LW$^{0.75}$)			
Cr - CIA	81.42±5.14	80.37±2.03	0.0001
Cr - ISD	81.46±5.02	78.84±1.31	0.0001
Grazing behavior	179.19±20.07	116.76±12.77	0.0001

The SDM *per se* can influence intake and milk yield. Cowan and O´Grady (1976) showed that milk yield per cow was constant at SDM values higher than 2500 kg/ha, but below 2000 kg/ha both milk yield and grazing time were reduced. Therefore it was most probable that the cows in both our treatments were not exposed to intake limiting levels of SDM.

In view of the low levels of forage utilisation of the present study, an increase in stocking rates (SR) could be proposed as an alternative to increase animal performance per unit area. Higher stocking rates would eventually lead to higher levels of mineral nutrients extracted from the system, mainly N, that would put at risk the sustainability of the NG pasture, but not the NG+Ap pasture, due to the N input by BNF from *A. pintoi* (Thomas, 1992; Valles, 2001).

Table 7. 5. Calculated daily herbage intake on an organic matter, dry matter, and fresh matter bases, of F1 (Holstein x Zebu) cows grazing native grass pastures (NG) and NG associated with *A. pintoi* CIAT 17434 (NG+Ap).

Basis for calculation	Intake			
	kg/cow		kg/100 kg LW	
	NG	NG+Ap	NG	NG+Ap
Organic matter (from Table 7. 4)	8.031	8.176	1.49	1.46
Dry matter (90% OM)	8.923	9.084	1.66	1.62
Fresh matter				
Whole sward DM	26.030	29.931	4.84	5.34
Hand plucked herbage DM	31.298	37.615	5.82	6.71
Oesophageal extrusa DM	54.508	61.712	10.14	11.01

The quality of SDM, evaluated as a whole sward or as hand plucked herbage, was high enough not to present limitations to intake. The CP values were in all cases above the critical range of 6% to 8%, below which a N deficiency for rumen microbes can reduce intake. Also ISOMD figures were in the higher part of the range for tropical pastures, without or with legumes (Minson, 1990). This is in agreement with the results of Ibrahim (1994) for the nutritive quality of hand plucked samples of the grass and legume components of two *A. pintoi*-based associations grazed at two stocking rates.

The whole sward and hand plucked samples had more CP and were more digestible than the oesophageal extrusa material. While the hand plucking technique has several advantages over the oesophageal extrusa *e. g.* it is cheap, simple, rapid, and the samples are not altered by saliva or mastication, it is not free from the bias. This fact has precluded some researchers from using the hand plucking technique (Wallis De Vries, 1990). In the present case, the most probable explanation to the higher nutritive value of the hand plucked herbage is that the operator chose the most tender parts of the pasture, which were easier to harvest by hand.

Table 7. 6. Short term animal performance variables of F1 (Holstein x Zebu) cows grazing native grass pastures (NG) and NG associated with *A. pintoi* CIAT 17434 (NG+Ap). Values are means ± standard errors.

Variable	Pasture		Significance of difference
	NG	NG + Ap	
Milk production (kg/cow/day)			
Saleable milk yield (SMY)	8.5±0.8	7.9±0.8	0.0594
Calf milk intake (CMI)	2.2±0.1	2.4±0.1	0.0334
Total milk yield (TMY)	10.7±0.9	10.4±0.9	0.8103
Liveweight			
Calf daily gain (kg/head/day)	0.55±0.04	0.59±0.04	0.0779
Live weight (LW, kg/cow)	539±20	560±16	0.4026

7. 4. 2 Ingestive behaviour

In the OF cows BR were much lower and BS much higher than on intact animals. The big differences may be due to the different ways in which these figures were generated: the 5 intact cows were not fasted and their grazing patterns were the usual ones; on the other hand, there were only 2 fistulated cows, which were fasted for several hours previous to sampling, and their usual grazing pattern was interrupted by the fasting sessions.

7. 4. 3 Oesophageal extrusa

The differences in CP and ISOMD between treatments were evident and can be attributed to the significant contribution of *A. pintoi* to the botanical composition of the ingested material. It was expected that oesophageal extrusa would be of a higher nutritive quality than those of the whole sward and of hand plucked samples. The CP content of hand plucked herbage was very similar to that of the extrusa in both pasture treatments, which indicated some agreement between the operator taking the hand plucks and the observed cow which served as a guide to sampling. With respect to the ISOMD, the outcome was entirely unexpected since ISOMD values were much larger than those of the extrusa. Sample processing error could have played a role. Elimination of excess saliva and liquid from oesophageal extrusa samples could have eliminated highly soluble cell contents liberated from herbage by ingestive mastication. Besides, freezing of extrusa samples disrupted herbage cells that liberated their liquid cell contents upon thawing; this liquid was very difficult to recover, so it may have been possible that highly digestible material was also lost in this way.

The observed relationship between the content of *A. pintoi* and the CP content of the extrusa is remarkably close to that found by Ibrahim (1994) using extrusa from oesophageally fistulated steers grazing *B. brizantha*/*A. pintoi* pastures in Costa Rica. This suggest that *A. pintoi* has the capacity of maintaining its N contents in different management circumstances and ecosystems, which is a desirable trait if native grass pastures or degraded introduced grass swards are to be improved.

Hess *et al*. (2002) compared the legume contents of non-fistulated vs. fistulated steers that grazed *B. humidicola*/*A. pintoi* pastures with different sward attributes. They found that fistulated animals selected for the legume both in the rainy season and the dry season, whilst the non-fistulated steers selected against the legume in the rainy season, but selected for it in the dry season. Fistulated steers were fasted overnight prior to extrusa collection. Intact steers were not only not fasted, but the contribution of the legume to the diet was determined in faecal samples with the $^{12}C/^{13}C$ technique of Jones *et al*. (1979). Thus, it was possible that overnight fasting could alter the selectivity that grazing ruminants. In the present study the fistulated cows selected against the legume. This is at odds with Ibrahim's (1994) findings, since his steers selected mostly for the legume.

7. 4. 4 Organic matter intake

7. 4. 4. 1 Double and single marker techniques

The OM intake values for both treatments were lower compared with intake values expected from tropical pastures (Stobbs, 1975). On the contrary, the total daily milk production, about 10 kg/cow/day, was rather high compared with data from similar pasture types (Mannetje, 1997). This apparent contradiction may arise from the fact that the cows in both treatments were in the early stage of lactation and may have been drawing on body nutrient reserves to sustain a level of productivity superior to that indicated by their energy and protein intakes.

It is difficult to explain the low OM intakes found in the present study. It has been reported that in young herbage regrowth, intake is reduced if the DM content falls below 18% (Verité and Journet, 1970). Other evidence suggests that the moisture content of herbage does not limit intake unless the DM content falls within the 13% to 15% range (Stobbs, 1975). An experiment in which moistened herbage was fed indoors to cattle, resulted in a reduced DM intake, even when the moistened material was supplemented either with hay or with silage (Butris and Phillips, 1987). In other trials the DM intake was positively correlated (r=0.89) with forage DM content (12% to 25%) at several stages of forage maturity (John and Ulyatt, 1987).

The DM content of forages increases with age. In our case, 20 days of paddock recovery time produced a very young and nutritious herbage but with a very low DM contents, around 15%. Herbage intake on a Fresh Matter (FM) basis is always recorded in experiments, but it is rarely reported. In the present experiment, the FM intakes based on DM content of the SDM and hand plucked herbage were low, because the DM content were comparatively high for fresh young material, because herbage samples remained in the field for 1-2 h after cutting, which increased internal and external water loss rates. Oesophageal extrusa may have been exposed to contamination with saliva, increasing its moisture content. Furthermore, OF cows may ingest herbage that is different in botanical and chemical composition to that ingested by intact cows, which would also affect the moisture content of extrusa (Carulla *et al*., 1991; Hess *et al*., 2002).

The FM intake was higher in the associated pasture than in the NG treatment. Thus, the cows in the association ate more herbage FM, but not a higher amount of DM. The internal moisture of herbage is rapidly released from cells by mastication and maceration and readily absorbed by the rumen (John and Ulyatt, 1987), so it was unlikely that in our study the large amount of ingested FM may have had a bulk effect on rumen fill. Orr *et al*. (1997) demonstrated that bite mass, expressed in terms of FM, remained constant whether the sheep grazed ryegrass (*L. perenne*) or white clover (*Trifolium repens*). Therefore, bite mass, expressed in DM terms, may be determined by the amount of FM per bite.

The differences in OM intake between the NG and NG+Ap pastures, measured by marker techniques, seem to be unimportant in biological terms, since the values were very similar. A Costa Rican experiment (Abarca *et al*., 1999) reported similar intakes between the grass *Brachiaria brizantha* (3.25 kg OM/100 kg LW) alone and associated with *A. pintoi* (3.28 kg OM/100 kg LW); this difference, although biologically unimportant, was statistically significant ($P<0.05$).

The Costa Rican study and the present one showed that *A. pintoi* was unable to stimulate higher intakes of OM and instead, the legume only substituted for the grass. This was contradictory to the higher CP and ISOMD values shown by the SDM, hand plucked herbage and oesophageal extrusa samples from the NG+Ap pasture treatment, which could have suggested increased OM intakes, which were not achieved.

Poppi and Mc Lennan (1995) indicated that the net transfer of feed protein to the intestines of the grazing ruminant is often not complete, and losses occur in the rumen with grasses and legumes when CP exceeds 210 g of CP/kg of digestible OM. In the present study, the forage of both treatments exceeded that value. The product of 210 g of CP/kg of digestible OM times the DM digestibility produces the diet's CP above which losses in net transfer of ingested CP will occur, as a result of energy deficiency in the rumen. The values for both treatments were lower than those recorded for extrusa. According to Poppi and Mc Lennan (1995) if legumes can increase DM intake by at least 30%, they will supply sufficient intestinal protein to increase daily milk yield by 2.6 kg of milk/cow.

In view of the inability of *A. pintoi* to stimulate OMI, other complementary nutritional alternatives should be tested to find ways to make efficient use of the extra protein consumed by the cows. Adding corn grain to the diet would not only increase directly OMI, but it would also supply more energy to avoid CP wastage at rumen level (Poppi and Mc Lennan, 1995). This alternative would work mostly at the individual cow level, but it must be thoroughly evaluated economically before being tested in experiments.

7. 4. 4. 2 Ingestive behaviour

This method of estimating OMI from grazing behaviour also produced a difference in OMI in favour of the NG pasture, but the values were greater than those estimated with the marker methods. In fact, the value of OMI for the NG treatment may be outside the range of large intake values expected for ruminants grazing tropical pastures, and that of the NG+Ap may be in the upper end of that range (Minson, 1990). It is very likely that the use of intact cows and OF cows to estimate the different components of the intake formula led to a bias in the estimation of DMI. For this reason, intake estimations with marker techniques must remain the best choice to study DM intake from pasture.

The cows in the association encountered a pasture that allowed them to obtain a large bite, and reduced their biting rate. The contrary occurred with the cows in the NG pasture, perhaps because the cow reacted applying a large biting rate to compensate for the reduced BR but compensation was slight and OMI rates were higher for the association : 17.3 g/minute vs. 20.5 g/minute.

Fasted ruminants showed a higher drive to eat (higher intake rate, achieved by a larger bite size) than non-fasted animals and fasting also altered the composition of the diet (Newman *et al*., 1994). Fasting also alters the normal alternation of grazing and rumination and leads to longer grazing times, but not to differences in bite size (Greenwood and Demment, 1988). Chacón and Stobbs (1977) concluded that the effect of overnight fasting were small compared to those of sward characteristics, but warned that fasting had to be kept to the minimum essential for the achievement of a satisfactory eating rate. The sampling protocol with OF cows must interrupt grazing or paddock activities only for the time necessary to attach collection bags and collect the oesophageal extrusa. Brazilian researchers appear to have obtained good results without fasting the OF cows (Lima *et al*., 2001; Soares *et al*., 2001).

Our results coincide with the observations of Newman *et al*. (1994) with sheep, in that the intact animals showed lower OMI rates (18.9±2.2 g/minute) than those of the OF cows (24.1±2.0 g/minute), but this difference was produced by different biting rates as well as different bite sizes. Therefore, the overestimation of OMI by ingestive behaviour was perhaps due to the fact that overnight and day fasting stimulated the OF cows to eat larger bites and reduce their rate of grazing.

The length of time the experimental cows spent outside the pastures was 265 minutes/day. The approximate times for transit to and from the milking shed were 15 minutes, about 10 minutes for milking and 60 minutes for calf suckling. This left 190 minutes of time waiting to be milked. This period was longer than the approximately 120-130 minutes shown by Cowan (1975) to be the milking periods of their cows. This factor may well have contributed to the reduced grazing times of the cows of the present study.

7. 4. 5 Animal performance

A short term grazing trial cannot represent the animal performance of an entire year (Moore *et al*., 1989). Yet, it allows to relate short-term animal performance with pasture characteristics that permit to identify the type of management options to optimise forage acquisition by grazing cattle (Stobbs, 1975).

The difference in SMY between treatments in this short term trial, was very close to that reported for the whole lactation on chapter 6 of this Thesis. Perhaps the same nutritional factors that rendered the association less productive early in lactation, were the same for the whole milk production period. Nevertheless, herbage intake estimation must be made at various stages of the cow's lactation and at different times of the year to explain long-term treatment differences (Aroeira *et al*., 2001).

7. 5 Conclusions

1. The *A. pintoi*/native pasture association improved the nutritive quality of the SDM and oesophageal extrusa overt that of the NG pasture.
2. The nutritive quality of the NG control pasture was superior to expected values for tropical grass pastures. This fact contributed to the lack of differences in animal performance between treatments.
3. The OF cow selected for the grass to a greater extent than it selected for *A. pintoi*.
4. The fasting of OF cows led to biased estimates of BS and BR, overestimating OMI.
5. The association had GT and RT lower than those of the NG pasture, but both cases were in lower part of the scale of published reports, which may have led to the low OM intakes.
6. OM intakes were higher for NG than for NG+Ap, but the difference was small and of little consequence for milk production, which did not differ among treatments.

8

GENERAL DISCUSSION AND CONCLUSIONS

8. General discussion and conclusions

The pasture component of the Mexican dual-purpose systems (DPS) in the humid tropics consists mostly of native grass pastures that receive an inadequate management, which leads to low biological and economical efficiency of milk and calf production. To increase production per animal and per hectare is biologically possible through the introduction of exotic grass species and N fertilisation, but not realistic from an economical standpoint. However, the introduction of persistent legumes into the existing native pastures offers a means to economically increase production of the DPS without endangering the environment, leading to a technically and economically sustainable pasture agrosystem. In consequence, the objective of the present study was to determine the level of improvement that could be obtained from a native pasture by means of the introduction of the persistent legume *Arachis pintoi*, measuring variables on the soil, vegetation and animal performance and ingestive behaviour. The findings of this study were discussed in the preceding chapters. The present chapter highlights the main findings and their practical significance for the DPS of the Mexican humid tropics. Also mentioned are the research needs for the future that would respond to some of the questions generated by the present studies.

8. 1 Establishment

Our study showed that planting *A. pintoi* into native pastures (NG + Ap) with seed is cheap because it requires little labour. However, the seed is expensive and not always available, which is a setback for pasture improvement (Bouman and Nieuwenhuyse, 1999). The alternative is vegetative planting with a higher planting cost because of the labour requirement, but relatively cheap propagation material. For the time being, the latter would be the best choice, mainly due to the lack of seed and its price, but also because vegetative propagation is generally successful since most planted stolons sprout and produce plants and, no less important because Mexican farmers are familiar with this technique.

A. pintoi does not require the reduction of competition from existing pasture vegetation, because the legume, albeit slowly, propagates itself satisfactorily, taking care of its own persistence, and neither does it require fertilisation for good establishment.

Reduced tillage of the soil enhances *A. pintoi* establishment. However, it must not be applied to the whole area because this increases the cost of establishment. A strategy to reduce cost is to till strips of pasture for *A. pintoi* establishment, alternating with strips of native grass and in this way reduce cost by one half to two thirds, depending on the width of the legume strip. When *A. pintoi* planting density is high, a native grass/legume association can be obtained in a short time.

8. 2 Persistence and standing dry matter

A. pintoi CIAT 17434 flowers almost all year which assures high soil seed reserve levels. It also has a strong stoloniferous habit. Both traits permit not only the survival of the species, but also a strong dissemination over the pasture, in such a way that it can become the dominant species. However, this increasing dominance of the legume can lead to a declining standing dry matter (SDM) of the association. But in the present study the SDM of the NG+Ap pasture was always higher than that of the NG treatment. With time, the contribution of broad-leafed weeds increased probably as a result of the inability of native grasses to use the N fixed by the legume. This reflects a need to have companion grasses with higher N requirements and higher DM yield than the native grasses.

8. 3 Soil improvement

If non-fertilised native pastures like those of the present study are used intensively with higher stocking rates than those typical of the region, then soil N is depleted, reducing forage yields and stocking rates, and promoting weed invasion, making the system unsustainable (Bouman *et al*., 1999). Introducing *A. pintoi* into native pastures improved the C and N status of the soil, probably because there was a higher growth of the associated pasture, which was reflected by the higher SDM of the association. This increase in fertility could be used strategically to reach higher levels of milk and calf production without compromising the technical and economic sustainability of the DPS of the Mexican tropics, where fertilisation is almost nil. For example, once soil fertility is increased the pasture could be improved by over sowing more productive introduced grasses, that use more efficiently the accumulated N fixed by the legume. This coupled with the appropriate management to keep grass/legume stability, could lead to greater technical and economic sustainability of tropical dual-purpose systems.

8. 4 Pasture quality and animal performance

The main problem detected in this study was the low OMI in both treatments. This most probably led to inadequate energy levels in the rumen, so as to make efficient use of the extra protein that was being ingested by the cows in the association. It was suggested that the low intakes could have resulted from the high moisture content of the young leafy herbage ingested, since in DM terms pasture availability could not have limited intake, as suggested by the low pasture utilisation rates. Three alternatives to change this situation were suggested. First, to add extra energy to the diet by supplying a high energy feed supplement that would improve the use of the extra protein ingested in the association. Second, given the low levels of pasture utilisation, to increase the stocking rate, that would be unsustainable for the NG pasture but not for the NG+Ap where output N is being replaced by N_2-fixation (Thomas, 1992). Finally, to increase the length of pasture recovery to provide forage with higher DM content, that would increase the OM intake with a good level of herbage quality for the association. Of the three, the application of the first two would depend on financial returns for implementing them. The third alternative could be applied in the shortest term because it requires less economical inputs, but has the disadvantage of reduced digestibility.

8. 5 System impact

This research showed that introducing *A. pintoi* into the native pasture increased the amounts of C and N in the soil. While the extended introduction of this legume into native grass pastures would constitute a highly positive impact on the system, it would not benefit the economy of the farmer since the NG+Ap failed to increase saleable milk yield (SMY). At the present time the Mexican farmer receives no benefits for C sequestration by improved pastures, as there is no immediate prospect of implementing "payment for environmental services" in Mexican agricultural practice. Under this situation, dual-purpose farmers will not be attracted to incorporate persistent legumes like *A. pintoi* into their farming systems.

The net emissions of CH_4, NH_3 and NO_2 are possible environmental hazards originating from pasture improvement though grass/legume associations. The digestion system of the ruminants is a source of CH_4 which is a by-product of fermentative digestion. More CH_4 per unit of ingested metabolisable energy (15%-18%) is produced by low quality tropical pastures as compared to good quality temperate pastures (7%) like ryegrass (Preston and Leng, 1987; Mannetje 2003). The nutritional quality of the NG+Ap pasture was superior to that of the NG pasture. This would indicate a positive environmental impact of *A. pintoi* by reducing CH_4 emissions to the atmosphere if used to a larger extent in the pastures of the Mexican humid tropics.

Valles (2001) estimated N input of around 189 kg N/ha/year in pure *A. pintoi* pastures located in field 1. Considering an average legume content of 30% (1998 to 2001), this would give around 60 kg N/ha/year for the NG+Ap pasture, which would represent 6 kg/ha/year of NH_3-N for volatilisation and the same amount of NO_3-N being denitrified, of which about 5% would consist of NO_2 (Mannetje and Jarvis, 1990).

The above indicates that a positive impact on the environment would be expected of the extended use of *A. pintoi* in the native pastures of the Mexican humid tropics.

8. 6 Future research

The rapid rotation and seasonal variation in stocking rate used in this study led to a dominance of *A. pintoi* in the association, whose contribution to the botanical composition increased to an almost complete dominance in the years following the termination of this study. Therefore, it is necessary to find a grass or group of grass species and develop a grazing management system that can lead to a technically sustainable association of grasses with *A. pintoi.* An approach would be to experiment with the "variable stocking rate/variable alternate rotation" design of Spain *et al*. (1985) to keep *A. pintoi* in an "optimum" range of 25%-35%.

It will also be important to continue monitoring the levels of C and N in the soil induced by *A. pintoi*, to corroborate the findings of the present study on a long term basis. The N enrichment of the soil may be advantageous to the farmer, as it opens the possibility of the successful introduction of exotic grasses, increasing the DM yields and maintaining a high carrying capacity. Also, even though it is not customary among Mexican DPS, forage maize for silage can be planted on areas where *A. pintoi* became dominant, to obtain high DM yields without the use of costly N fertiliser. The high soil seed reserves would allow the persistence of the legume.

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SUMMARY

Introduction

Native pastures dominated by grasses constitute about 50% of the grazing lands of the Mexican humid tropics dedicated to dual-purpose (milk and calves) production systems (DPS), in which European x Zebu types of cattle predominate. These pastures have low levels of production because of inadequate management. Research in Central and South America has shown that under heavy grazing *Arachis pintoi* is a persistent and productive pasture legume that fixes N_2 effectively and also adapts well to humid tropical conditions. Exotic grasses are expensive to establish because of high seed cost and expensive to maintain due to their high requirement of fertiliser N to maintain production, so they are not likely to be adopted to a great extent by DPS farmers. Therefore, it was proposed that the best way to improve pasture productivity in the Mexican humid tropics would be by introducing *A. pintoi* into existing native pastures. The objectives of this study were to assess the level of improvement in the soil, the pasture and animal performance by implementing this proposal.

Materials and methods

The experimental site is located in the eastern coastal plains of the Gulf of México in the State of Veracruz. The mean annual rainfall is 1915 mm and mean temperature 23.4 °C. The soil is an Ultisol, acid (pH 4.1-5.2), with low contents of P (< 3 ppm). The establishment experiments were conducted between 1992 to 1996. The grazing study was conducted from January 1998 to December 2001.

The treatments were the native pasture grass-dominated control (NG) and the NG into which *A. pintoi* was introduced (NG+Ap). The stocking rate was 2 cows/ha during the critical period (October/December - June/August) of the year and 3.2 cows/ha for the remaining favourable herbage season, in which extra cows were introduced to consume the extra forage, and

were withdrawn whenever the standing dry matter (SDM) fell below 2500 kg /ha in any paddock, generally by the end of the year or the beginning of the next. Rotational grazing of 1 day occupation and 20 days of recovery was applied throughout the trial. No fertiliser was applied during the trial.

Several establishment treatments tested the effects of herbicide, tillage, fertilisation slashing and burning, use of vegetative material versus seed and cultivar on plant height, plant number and soil covered by the legume.

A. pintoi persistence was evaluated in terms of stolon length, rooted nodes, soil seed reserves, and plant and seedling survival.

SDM and botanical composition were monitored.

Soil samples were analysed for pH, C and N contents and bulk density. The live weight of cows their saleable milk yield, calf weights and their milk intake were recorded.

The *in situ* organic matter digestibility (ISOMD, %) and crude protein (CP, %) contents of the SDM, of hand plucked samples drawn from the SDM and of oesophageal extrusa were determined. Organic matter intake (OMI) and OM digestibility were determined with the use of external and internal markers. Grazing (GT), ruminating (RT) and other activities times (OAT) were observed. Bite size (BS) and biting rates (BR) were measured on oesophageally fistulated (OF) and intact (IC) cows.

Results

Establishment

Neither reduced tillage nor no tillage with or without fertilisation produced differences to reach 50% cover, 20 weeks after planting. P fertilisation did not improve establishment whether pasture vegetation was controlled by slashing or glyphosate spraying in combination with burning or not burning after vegetation control. The best vegetation control was obtained with glyphosate. There were no differences in establishment between the *A. pintoi* CIAT's accessions 17434, 18744, 18748.

Persistence

Flowering, stolon length, rooted nodes and seed reserves increased with time. In the third year, the mean length of stolons was 48 m/m^2 and the seed reserves 765 kg/ha. Plant survival was about 90% from November 1999 to December 2001, but seedling survival was practically nil.

Standing dry matter and botanical composition

The NG+Ap pasture always had higher SDM than the NG control within each study year, but regardless of the treatment the SDM was highly seasonal, reaching on the average the highest value (4.1 ton of DM/ha) in August and the lowest (2.7 ton of DM/ha) in December and January. *A. pintoi* increased from 15% in 1998 to 37% in 2000; in the same period, the native grasses decreased from 52% to 40%.

Soil carbon, nitrogen and bulk density

The NG+Ap pasture showed higher C and N values than those of the NG pasture. From the initial 18.3 t C/ha for both pastures in 1998, the C in the soil by 2001 had increased by about 7 t/ha/y and 8 t/ha/y for the NG and NG+Ap pasture treatments, respectively. The amount of N added to the soil by the NG+Ap pasture, based on an *A. pintoi* content of 30%, was about 60 kg/ha/y. Bulk density was not affected by treatments, remaining around 1.2 g/cm^3.

Animal performance

The effect of pasture treatments were not consistent on weight changes of the cows. The reproductive efficiency of the cows was similar during the experiment with 80% pregnancy rate. The saleable milk yield (1376 kg/cow/lactation), the daily milk intakes (3.5 kg/calf/day) and the weight gains of the calves (0.5 kg/calf/day) were similar between treatments.

Herbage quality and ingestive behaviour

The dry matter content of the NG+Ap was lower than that of the NG control, whether it was measured in SDM (30% vs. 34%), hand plucked herbage (24% vs. 26%) or oesophageal extrusa (15% vs. 16%). The degree of utilisation of the pasture was around 12% for both pasture treatments. The ISOMD was always higher in the association than on the NG pasture: 69% vs. 64% in the SDM, 80% vs. 71% in the hand plucked herbage, and 62% vs. 57% in the oesophageal extrusa. The CP values followed a similar trend as the ISOMD, with values always higher than 8%. The *A. pintoi* content of oesophageal extrusa (38%) was lower than that of the SDM (44%). The GT and RT were lower in the NG+Ap (395 and 376 min/day) compared to those of NG (457 and 406 min/day). The BR of intact cows was lower in the association (41 vs. 51 bites/min), but that of oesophageally fistulated cows did not differ between treatments (29 bites/min). The BS of intact cows was higher in the association (0.3 vs. 0.5 g of OM/bite), while that of oesophageally fistulated cows was similar among treatments (0.8 g of OM/bite). Organic matter intakes of cows were very similar between pasture treatments (1.46 -1.49 kg /100 kg LW). Intake on a fresh matter basis was also comparable (10 - 11 kg /100 kg LW).

Future research

As *A. pintoi* shows a strong tendency to dominate the pasture under grazing, there is a need to find introduced grass species that can curb *A. pintoi* and adapted management to keep an optimal range (25% - 35%) of legume in the sward. OMI was low and means to increase it by supplementary energy feeding or changes in stocking rate or longer periods for pasture recovery should be investigated. The feasibility of introducing exotic grasses or planting forage crops, making use of the increased N content in the NG+Ap soil should also be investigated.

Conclusions

The most economical way to introduce *A. pintoi* into the native pastures is planting in strips with vegetative material without soil tillage, fertiliser or herbicide treatment.

In spite of *A. pintoi* having improved the nutritive quality of the available forage as well as that of ingested herbage, it did not increase the productive performance of the dual-purpose cows.

On the other hand, the introduction of *A. pintoi* did increase the C and N contents in the soil, which constitutes an environmental asset in the dual-purpose systems of the Mexican humid tropics.

SAMENVATTING

Inleiding

De helft van de graslanden in de humide tropen van Mexico die voor veehouderij met voornamelijk Europese x zebu rassen voor gecombineerde melk- en vleesproductie wordt gebruikt bestaat uit onverbeterde graslanden. Productie van deze graslanden is laag vanwege ontoereikend beheer. Onderzoek in Centraal en Zuid Amerika heeft aangetoond dat *Arachis pintoi* een standvastig en productieve graslandvlinderbloemige is dat effectief N_2 bindt en goed is aangepast aan beweiding in de humide tropen. Exotische grassen zijn duur vanwege hoge zaadkosten en vanwege hun hoge N behoefte om hun productiviteit in stand te houden. Die worden dus niet gauw gebruikt voor gecombineerde melk- en vleesproductie. Om deze reden werd voorgesteld dat het introduceren van *A. pintoi* in bestaande onverbeterde graslanden de beste manier zou zijn om de graslandproductiviteit in de humide tropen van Mexico te verhogen. Het doel van deze studie was om het effect van deze maatregel op de verbetering van de bodem, het grasland en de dierlijke productie te toetsen.

Materiaal en methoden

De plaats van het onderzoek bevindt zich in de oostelijke laagvlakte van de Golf van Mexico in de Staat Veracruz. De gemiddelde jaarlijkse regenval is 1915 mm en de gemiddelde temperatuur 23.4 °C. De bodem is een zure Ultisol, (pH 4.1-5.2), met laag P gehalte (< 3 ppm). De proeven voor aanleg werden uitgevoerd tussen 1992 en 1996 en de beweidingproeven van januari 1998 tot december 2001.

De behandelingen waren onverbeterd grasland (OG) en OG waarin *A. pintoi* was geïntroduceerd (OG + Ap). De beweidingdichtheid was 2 koeien/ha in de kritische grasgroei periode van het jaar (october/december – juni/augustus) en 3.2 koeien/ha voor de overige, gunstige grasgroei periode, wanneer extra koeien werden toegevoegd aan de percelen. Zij werden weer verwijderd wanneer de hoeveelheid gras op stam (GOS) beneden 2500 kg/ha droge stof kwam. Dit vond meestal plaats rondom de jaarwisseling. Omweiden met 1 dag beweiden en 20 dagen rust werd gedurende de gehele studieduur toegepast. Er werden geen meststoffen gebruikt.

Met verschillende aanlegbehandelingen werden de effecten getoetst van herbicide, grondbewerking, bemesting, toppen, afbranden, gebruik van vegetatief plantmateriaal of zaad en cultivar op aantallen planten, plant hoogte en bodembedekking door de vlinderbloemige.

De standvastigheid van *A .pintoi* werd geëvalueerd in termen van stolonlengte, aantal bewortelde knopen, bodemzaadreserve, en overleving van oorspronkelijke planten en zaailingen. Hoeveelheid GOS en botanische samenstelling werden regelmatig bijgehouden. Grondmonsters werden geanalyseerd op pH, C en N gehaltes en bodemdichtheid. Het levend gewicht van koeien, hun verkoopbare melkopbrengst, kalfgewichten en hun melk inname werden vastgelegd. De *in situ* organische-stofverteerbaarheid (ISOMV) en ruweiwit (RE) gehaltes van GOS, handgeplukte monsters van GOS en slokdarmmonsters werden bepaald. Organische-stof opname (OSO) en -verteerbaarheid (OSV) werden geschat met onverteerbare interne en externe hulpmiddelen. Graastijd (GT), herkauwtijd (HT) en tijd besteed aan andere activiteiten werden geobserveerd en vastgelegd. Beetgrootte (BG) en bijtsnelheid (BS) werden waargenomen bij slokdarmfisteldieren en intacte dieren.

Resultaten

Aanleg en vestiging van A. pintoi

Er waren geen effecten van grondbewerking met of zonder kunstmest toediening op het bereiken van 50% bodembedekking door *A. pintoi* 20 weken na planten. P bemesting leidde niet tot verbetering van de vestiging van *A. pintoi* of de vegetatie die nu al of niet werd teruggedrongen door toppen , met of zonder glyphosate bespuiting in combinatie met al of niet afbranden. Uiteraard werd de beste vegetatiebeheersing verkregen met glyphosate bespuiting. Er waren geen verschillen tussen *A. pintoi* cultivars CIAT 17434, 18744, 18748.

Standvastigheid van A. pintoi

Bloei, stolonlengte, aantal bewortelde knopen en bodemzaadreserve van *A. pintoi* namen met de tijd toe. In het derde jaar was de gemiddelde stolonlengte 48 m/m^2 en de zaadreserve 765 kg/ha. De overleving van oorspronkelijk planten was ongeveer 90% van november 1999 tot de laatste waarneming in december 2001, maar die van zaailingen praktisch nihil.

Gras op stam en botanische samenstelling

OG + Ap had altijd een hogere GOS dan OG, maar beiden vertoonden seizoenschommelingen, met de hoogste opbrengst (4.1 t DS/ha) in augustus en de laagste (2.7 t DS/ha) in december en januari. Het aandeel van *A. pintoi* nam toe van 15% in 1998 tot 37% in 2000 en in dezelfde periode nam dat van de grassen af van 52 tot 40%.

C, N in de bodem en bodemdichtheid

OG + Ap had hogere gehaltes aan C en N dan OG. De oorspronkelijke hoeveelheid C van 18.3 t/ha voor beide graslandtypen in 1998 steeg met 8 t/ha/jaar in OG + Ap en dat van OG met 7 t/ha/jaar tot de laatste waarneming in 2001. De hoeveelheid N toegevoegd aan de bodem door OG + Ap, gebaseerd op 30% *A. pintoi* in het grasland was ongeveer 60 kg/ha/jaar. De bodemdichtheid bleef voor beide behandelingen ongeveer 1.2 g/cm^3 .

Dierlijke productie

Het effect van graslandtype was op de levende-koegewichten was zeer variabel. De reproductie van de koeien (80% drachtigheid), de verkoopbare melkopbrengst (1376 kg/koe/lactatie) en de dagelijkse melkinname van de kalveren (3.5 kg/kalf/dag) waren vergelijkbaar tussen de graslandtypen.

Ruwvoer kwaliteit en graasgedrag

Het percentage droge stof van OG + Ap was lager dan dat van OG in GOS (30 vs 34%), in handgeplukte monsters (24 vs 26%) en slokdarmmonsters (15 vs 16%). De graslandbenutting was ongeveer 10% voor beide graslandtypen. De ISOSV was altijd hoger in OG dan in OG + Ap in GOS, (69 vs 64%) in handgeplukte monsters (80 vs 71%) en in slokdarmmonsters (62 vs 57%). De RE gehaltes waren vergelijkbaar in de graslandtypen met waarden altijd boven de 8%. Het *A. pintoi* gehalte van de slokdarmmonsters (38%) was lager dan dat van GOS (44%). GT en HT waren lager in OG + Ap (395 en 376 min/dag) dan in OG (457 en 406 min/dag). De BS in intacte koeien was lager voor OG + Ap dan in OG (41 vs 51 beten/min), maar dat van slokdamfisteldieren vertoonde geen verschil (29 beten/min). De BG van intacte koeien was hoger in OG + Ap dan in OG (0.3 vs 0.5 gOS/beet) terwijl die van slokdarmfisteldieren vergelijkbaar waren tussen graslandtypen (0.8 gOS/beet). OSO van de koeien en opname van vers gras waren vergelijkbaar tussen graslandtypen (respectievelijk 1.46 – 1.49 en 10-11 kg/100 kg levend gewicht).

Toekomstig onderzoek

Aangezien *A. pintoi* een sterke neiging heeft om grasland te domineren onder beweiding is het nodig om exotische grassen te vinden die daar tegen opgewassen zijn en aangepast beheer te ontwikkelen om het optimale gehalte van *A. pintoi* in het bestand (25 – 30%) te handhaven.

OSO was laag en maatregelen om het te verhogen met supplementaire energievoeding, veranderingen in de beweidingdichtheid of verlenging van de rustperiode zouden moeten worden onderzocht.

De mogelijkheid zou ook onderzocht moeten worden om exotische grassen te introduceren of om voedergewassen te telen, gebruik makende van de verhoogde N status van de OG + Ap bodem.

Conclusie

De goedkoopste manier om *A. pintoi* te introduceren in bestaande graslanden is deze in banden te planten met vegetatief materiaal zonder grondbewerking, bemesting of herbicide behandeling.

Ondanks het feit dat *A. pintoi* de voedingswaarde van het ruwvoer op het land en dat van het opgenomen ruwvoer verhoogde heeft dit niet geleid tot hogere productiviteit van de gecombineerde melk- en vleesproductiekoeien. Maar de introductie van *A. pintoi* heeft wel geleid tot verhoging van de C en N gehaltes van de bodem. Dit is een ecosysteemverbetering in het gecombineerde melk- en vleesproductiesysteem.

CURRICULUM VITAE

Epigmenio Castillo Gallegos was born on November 30, 1952 at Monterrey, Nuevo León, México. He received a B. Sc. degree in Agronomy with major in Animal Science, from the Faculty of Agronomy of the Autonomous University of Nuevo León in 1974. After graduation he was employed by a private beef farm for two years and after that he joined the National Institute of Animal Science where he engaged in tropical pasture research. From 1980 to 1983 he studied for and was awarded a M. Sc. degree in Agronomy by the University of Florida. Between 1983 and 1985 he was a researcher at the center for Animal Sciences of the Postgraduate College, where he taught pasture and forage production at the graduate level. Since 1986 he works for the Facutly of Veterinary Medicine and Zootechnics of the National Autonomous University of México, where he has been teaching forage management at the undergraduate level and doing research on tropical pastures. Since 1994 he has been working with Professor L. 't Mannetje on his doctoral thesis. This research was conducted at the Center for Education, Research and Extension on Tropical Animal Husbandry at Martínez de la Torre, Veracruz, México, with the support of The National University, The University of Wageningen and SIGOLFO, the regional branch of the National Council for Science and Technology.