Bangor University

DOCTOR OF PHILOSOPHY

Evaluation of the role of trees and shrubs in seasonally dry pastures of Colombia

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Award date:
2002

Awarding institution:
Bangor University

Link to publication

Evaluation of the role of trees and shrubs in seasonally dry pastures of Colombia.

**A thesis submitted in candidature for the degree of
Philosophy Doctor
of the University of Wales**

By

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2002

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Dedication

To the memory of my beloved father

ACKNOWLEDGEMENTS

The research presented in this thesis was undertaken through a split programme at the University of Wales, Bangor and at the national research Centre of Turipaná-CORPOICA, Cereté-Córdoba, Colombia. The study involved both field trials and laboratory research. Inevitably, this type of research implied the participation of many people without whose valuable help - financial, technical, logistical and moral - I would not have been able to complete.

In particular and specially I would like to express my deepest gratitude to those who worked beside me and made this achievement come true. Working with Dr. Fergus Sinclair as my supervisor has been an enriching experience. His guidance, experience and knowledge to conduct me through agroforestry research will be something to keep always in my life. I will never forget his encouragement to convince me to start my research from the farmers' knowledge and the enthusiasm he always devoted to come to Colombia, even in the most difficult situations of my country, he visited me to discuss my research on the ground, this was very stimulating and encouraging. I highly appreciate his support and patience to attend and sort out all the numerous financial, logistical and health difficulties I had through my studies. He always found the proper words in the most difficult moments to raise my spirits and keep me going. In the same vein I am deeply indebted to Dr Michelle Jones, for being always there when I needed her help. Her patience, personal interest in this study, encouragement, guidance and kindness in both situations, when I was in Colombia or in Bangor made it possible for me to complete all tasks. Her numerous suggestions and all I learned from her will be something to remember forever. I also feel a need to thank her not only for her help in my studies, but also for the kindness she and her family, Dr John Healey, Sacha and Nat gave me during my school life and in times of difficulties, their encouragements made life bearable. I am very much obliged to Mr Blas Panza, my technician in Colombia. I would never have been able to do the enormous amount of fieldwork implied in this research without the interest, responsibility, efficiency, sense of humour and optimism he always demonstrated through all of these years. I have no words to thank him for his sacrifice to leave his family every week to come to the research centre to work with me, taking the risk of travelling under the difficult circumstances of our country. He was always willing to work for very long days and nights to complete our tasks and during my absences from Colombia he looked after the multistrata experiment with an incredible professionalism and responsibility. His patience and courage and valuable suggestions to face all difficulties gave me strength to continue until the end. I must also thank his wife Rina and his children Andres Camilo and Maria Camila for their understanding and patience during Blas' absences of all these years.

Beside Blas I had the invaluable participation of Rafael Argumedo, Ausberto Mogollón, Andrés Velasques and Rusbel Jimenez. During my fieldwork I got a lot of assistance from them. This implied days and nights of total dedication to be working. They did it with enthusiasm and responsibility and all of them played a very important role to enable me to finish this research, so I want to express my sincerest gratitude not only to all of them but also to all temporary workers that helped me in different ways in the field.

Special thanks go to the farmers I interviewed during the survey in the Caribbean region of Colombia, whose warmth and ever willingness to share their experience and knowledge has left on me an unforgettable impression. Indeed, it was a great experience to learn from them. Thanks are also due to Mr Galo Gamero who assisted me with the farm information and to Mr Freddy Neira for his help with the microregion and soils maps. I would also like to acknowledge the friendship, assistance and support received from Mr Antonio Sfer for driving me through all the microregions.

I am very proud of having had the opportunity to discuss some topics of my research with Dr John Hall. His encouragement, constant advice, guidance, patience, kindness and willingness to make suggestions and help in my studies deserve all my gratitude and appreciation.

The research could not have been accomplished without the generous help of some people in Turipaná Research Centre during the various stages of fieldwork in Colombia. I would particularly like to thank Mr Amauri Petro, Miguel Ortega, Francisco Almanza, Francisco Mangones, Johan Mangones, Manuel Caballero, Jairo Pernet, Fidel Negrete, Jesus Maza, Miguel Regino, Leonardo Alvarado, Yesid Abuabara, German Mendoza, Rubiel De Vargas, Emilio Soto, Enrique Vergara and Silvio Pico. I would like also to thank to Mrs Betty Abadia and her assistances for helping me with the ammonia and tannin analysis at the Nutritional Laboratory in Tibaitatá research Centre. All my gratitude goes to Anton Turner who helped me immensely to establish the multistrata systems, I must also thank him and his family who made sure I felt at home during my stays in The Breaks. Special thanks go to Craig Allan for his friendship and all his help with the single tree plot measurements.

I am also indebted to Dr Bob Mayes and Mr Stuart Lamb of the Macaulay Land Use Research Institute in Aberdeen, who introduced me to the *n*-alkane technique and their constant advice and guidance made it possible for me to complete the feed intake task. During the nitrogen analysis in Bangor, I got a lot of assistance from Dr Andy Owen for which I am indeed grateful. The enormous assistance and co-operation received from Dr Vikki Grime in the sap flow research is greatly appreciated.

Since the first time I arrived in Bangor Karen Cooper and her family helped me in many different ways. Karen not only looked after my personal needs but also assisted me with an enormous amount of typing when I was limited by health problems. Her kindness, friendship and encouragement will be things to remember forever.

I have no words to thank the support and warm friendship received from Dr Sandy Williams, Dr Bonnie O'Brien, María Teresa Baiges and Delyth Owen. I will never forget the kindness of all of them in looking after my health and all they did to make me feel at home during my times in Bangor.

I had the fortune to have an inestimable moral support of some friends in Colombia, and all my gratitude goes to Carlos Sanchez and his family, Luis Carlos Arreaza, Diana Arboleda and her daughters. I have specially to thank to the "Abuelita", Cielo Yañez and Adela Rodriguez for her immense help providing the meals for the British students, my technician and workers. Special recognition and gratitude goes to my friend Judith Martinez who helped me in Colombia in one way or another while I was in Bangor.

To Helga Dixon, Emma Youde, Kurt Maclaren, T.P. Tiwari, Mohammed Al-Amin, Wasantha Seneviranthna, Sunethra Thennakoon, Judith Ramos, Lorna Manson, Gwladus Thomas, Maureen Evans, Beverly Jones, Donna Williams, Dil Sherchan, Diane Moreland, Penelope Draw, Martine Ngobo and Sara Namirmbe thanks for your moral support and friendship.

Dr Anne Hoffman generously tried to improve my health. For her kindness, dedication and patience in helping me to continue until the end, I will be eternally grateful.

I acknowledge gratefully Corpoica, Colciencias, Fondo Nacional del Ganado, Ministry of Agriculture of Colombia and the University of Wales, Bangor for the financial assistance, and I would like to express my special thanks to Dr Tito Diaz, the director of the scientific division of Corpoica, Dr German Afanador, former director of Cattle Plan, and Mr. Arturo Vega, the current Corpoica regional director for their help to find funds and supporting my research. My gratitude goes also to Mrs Beatriz Escobar former director of Corpoica regional 2 for her support and encourages starting my studies.

Last, but not least, with all my love I must thank my sisters, brothers, nieces and nephews, especially my mother and Mateo whose moral support and love, not diminished by physical distance, gave me strength in difficult moments. To Lorena, Dina Maria, German and Cecilia for their constant messages to encourage and keep my spirits up, all my love and gratitude.

ABSTRACT

The thesis presents an investigation of tree, pasture and cattle interactions in multistrata silvopastoral systems on seasonally dry pastures in Colombia. The research began with a participatory appraisal of the existing silvopastoral practices in the region and farmers' attitudes towards the trees already in the landscape. A survey was conducted involving 54 farms in the Caribbean region of Colombia (West of the Magdalena River) and revealed much greater and more deliberate use of trees on pastures than had previously been recognized. This confirmed that asking farmers about their current knowledge and practice is an essential prerequisite to design of research that is relevant to their needs. Farmers' knowledge about trees and scientific consideration of the trees present in pastures highlighted the importance of different functional roles of trees, occupying different strata, particularly with respect to production of fruit for cattle fodder as well as leaf browse.

A preliminary single tree plot experiment measuring the effects of 10 tree species on pasture productivity and soil moisture revealed that the overall pasture dry matter in the vicinity of trees was different for different tree species. This confirmed that choice of tree species for use in silvopastoral systems may have a large impact on understorey productivity particularly in the dry season and, therefore, is an important management consideration for farmers.

A large systems experiment was designed, based on the results of the farmer survey, to investigate the effect of planting trees of different stature and productive function (sources of leaves, fruit or timber) into pasture. The experiment was established on 30 ha of cattle-grazed pasture, using four treatments of differing structural complexity made up of combinations of vegetative layers or strata (pasture layer-*Dichanthium aristatum* and *Brachiaria mutica*, shrub layer-*Crescentia cujete*, *Gliricidia sepium* and *Leucaena leucocephala*, arboreal tree layer-*Albizia saman*, *Cassia grandis* and *Guazuma ulmifolia* and timber tree layer-*Pachira quinata*, *Swietenia macrophylla* and *Tabebuia rosea*), plus a pasture control. The target density of plants was higher for lower stratum species (625, 156 and 39 trees ha^{-1} for shrubs, arboreal and timber trees respectively) and a substitutive design was used where multiple strata were combined. High survival and fast growth of trees planted into pasture demonstrated that productive associations of trees on grazed pasture could be established. Higher growth rates of shrubs and arboreal trees were observed when they were mixed with other strata than when grown alone with pasture. In contrast, there was no detectable effect of the addition of trees on either pasture biomass or compostion over a two-year period. However, pasture biomass and composition were both heavily influenced by season, with markedly less biomass in the dry season. This demonstrated that high tree densities could be established in this environment without immediate reductions in pasture productivity.

There was also evidence of differences in diet quality amongst treatments. In terms of the nutritive value of components, the potential degradability of *Dichanthium aristatum* was higher when it was grown in the more complex systems containing shrubs and trees than in the pasture control. This was associated with higher nitrogen content of dry season diets including tree leaf material which may have enhanced rumen function. Estimation of feed intake using the *n*-alkane technique indicated that up to about half of the dry season diet could be provided by shrub fodder confirming that browse species have large potential as a food source for ruminants, on seasonally dry pasture.

The overall impact of adding trees to pasture was to increase animal productivity. Milk yield per cow in the dry season was higher in agroforestry treatments than in the pasture control, consistent with higher quality diets in agroforestry treatments. There was also a marked increase in milk yield per hectare irrespective of season as a result of higher stock carrying capacity on agroforestry plots, consistent with higher overall forage biomass productivity in plots with trees or shrubs.

The research has revealed considerable potential for using trees to improve and sustain cattle productivity on seasonally dry pastures. These results are discussed in the light of ongoing development of silvopastoral systems in the Caribbean region of Colombia.

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CHAPTER 1

1. GENERAL INTRODUCTION

1.1 Rationale and justification

Conversion of primary forest to pasture is widespread in Latin America and the removal of trees has often been accompanied by land degradation, declining productivity and eventually abandonment. There are between 20 and 35 million ha of abandoned pasture in the Amazon basin alone (Serrao and Toledo, 1990). Deforestation is one of the most serious environmental problems in Colombia, which has the third-highest rate of closed forest loss in South America, brought about by cattle ranching and expanding agricultural colonisation (WWF, 1998). Retaining and managing trees in pastures has been suggested as a means to improve the productivity and sustainability of livestock production systems, especially in seasonally dry climates, through the provision of dry season cattle fodder from tree leaves and fruit (Humphreys, 1994), increased nutrient cycling and improvement of soil structure (Young, 1997) and the provision of shade for livestock, which may reduce heat stress and increase feed intake (Daly, 1984). Isolated trees on farmland are also now being recognised as important elements of fragmented forest canopy, contributing to the conservation of biodiversity in Latin America (Guevara et al., 1998).

The present research was conducted under the auspices of the national agricultural research system in Colombia in the Caribbean region of the country. Pasture degradation is one of the main factors contributing to the low biological efficiency expressed as prolonged age at first calving (36-40 months), low production per lactating (800-1140 l cow^{-1}), long calving intervals (420-470 days) (Pérez et al., 1998); this factors amongst others result in an economic inefficiency ((high cost per head per hectare, i.e. losses per cow per year 54 USD, Navarrete et al., 1993)). In most of the areas where cattle are raised, several years of subsistence cropping practice (mainly cotton) elapse before pasture is established. Amongst environmental factors, most limiting is soil fertility (Serrão and Toledo 1992). Technology available for the improvement of cattle production implies establishment of improved grasses, fertilization and weed control. According to Serrão and Toledo (1992) the limited success in the adoption of these high input technologies is as a result of a) economic feasibility being possible only under subsidized conditions, which are infrequent in developing countries; b) reclaimed pastures being based on forage species and cultivars with only limited adaptation to naturally poor soil conditions (as is in the case of *Panicum maximun* cv. Coloniao and to a lesser extent, *Brachiaria brizantha* cv. Marandua) or to the prevailing biotic pressures (such as spittlebug herbivory on *Brachiaria humidicola*, and particularly *Brachiaria decumbens*). Consequently, improved grass pastures remain prone to degradation and their stability eventually depends upon relatively high investments in maintenance, fertilization and weed control.

A contributing factor to low biological productivity is the inability of tropical grasses to support a level of animal production comparable with temperate grasses that has generally been ascribed to lower nitrogen and poorer digestibility (Minson, 1982). A series of attempts have been made to enhance productivity from tropical pastures and subsequently animal production. It is now widely accepted that some shrubs and trees may contribute to animal diets (Leng et al., 1992b; Humphreys, 1994). Browse species often have higher nutrient content than grasses (De Leeuw and Chara, 1985; Aletor and Omodora, 1994) but may also contain antinutritive factors (Kumar and D'Mello, 1995; Whetton et al., 1997). Because of their deep rooted, perennial nature, coupled with high leaf biomass production, browse species can often be utilised at times of the year when herbaceous fodder is scarce and of low quality thereby increasing the efficiency of utilization of the basal diets for livestock, which, in the tropics, generally comprises of low-nitrogen pastures and poor-quality crop residues (Aletor and Omodora, 1994).

Leaves and fruits of trees and shrubs have provided valuable forage to grazing animals since the time of their domestication (Robinson, 1985). Shrubs and trees are the most visible plant forms in many landscapes (Mckell, 1980). However, they have been neglected in most scientific research on pasture improvement and efforts have concentrated on methods for their eradication from pasture rangelands (Gutteridge and Shelton, 1994). At least 75% of the shrubs and trees of Africa serve as browse plants and many of these fix nitrogen (Skerman, 1977). In Southeast Queensland in Australia, stands of *Acacia aneura* sustain the sheep industry in times of drought (Everist, 1969). In Latin America, natural stands of *Leucaena leucocephala, Gliricidia sepium, Prosopis juliflora, Calliandra callothyrsus, Albizia saman Crescentia cujete* and *Guazuma ulmifolia,* amongst others, provide the only available forage and fuelwood in many of the more arid and semi-arid areas (Altieri, 1995; Escalante, 1995; Cajas-Girón and Sinclair, 2001). Most of these species retain their leaves throughout the dry season, making fodder (leaves and pods) available when, as a feed resource, herbaceous plant scarcity is a major constraint faced by farmers (Cajas-Girón and Sinclair 2001).

Recent studies suggest that the incorporation of woody plants into farming systems may increase economic productivity and environmental sustainability (Michon, 1999). The introduction of trees into farming systems offers farmers the advantage of crop diversification, providing valuable outputs such as fodder from leaves and fruits, as well as shade and wood products, increasing the income of the farm. Livestock productivity that is constrained by scarcity of pasture, especially during the dry season, may be improved by increasing tree cover on pasture. Additionally the presence of trees in the farming system may provide important functions for the sustainability of the system, involving a series of services including erosion control and maintenance of fertility, improving the efficiency of use of resources (light, water and nutrients) and benefits stemming from biological interactions between the different components of the farming system such as nitrogen inputs from biological fixation and biological control of weeds and diseases (Cannell, 1985; Young, 1997; Belsky, 1994).

Silvopastoral systems are land use practices which involve the deliberate combination of trees (including shrubs, palms and bamboos) and animals on the same land management unit in some form of spatial arrangement or temporal sequence such that there are significant ecological and economic interactions between tree and livestock components (modified after Sinclair, 1999). These land use systems are generally characterised by higher productivity than those of open pasture, on account of the vertical stratification above and below ground of the different components. In addition, trees in species mixtures can potentially bring about "micro-site enrichment" through processes such as efficient cycling of plant nutrients and nutrient pumping (Sanchez, 1995).

The introduction of agroforestry systems, especially silvopastoral systems, into developing countries is often hindered by fears that trees will reduce the yields of the pasture (Belsky et al. 1993a). Although some studies have found this to be the case (Somarriba 1988; Jackson et al. 1990), trees in other areas have been found to increase rather than decrease understorey pasture productivity (Radwanski and Wickens 1967; Wilson et al. 1986; Belsky et al. 1989 and Belsky et al. 1993b). Shrub and tree species having differing characteristics may differ in their effects on understorey production: some species might have beneficial effects depending on features such as crown type (dense or sparse), ability to fix nitrogen, provision of a significant amount of fodder biomass, (not only in terms on quantity but also of high quality). Beneficial effects depend on tree density; as herbaceous-layer productivity changes curvilinearly with increasing tree density (Knowles , 1991). Low densities may increase understorey plants by increasing soil fertility and improving water balance of plants growing in the shade (Jackson et al., 1990; Isichei and Muoghalu, 1992). At higher densities, trees might reduce herbaceous biomass productivity by sequestering nutrients in standing woody biomass and by competing with understorey vegetation for light, nutrients and water (Belsky and Amundson, 1992). The pasture understorey is a valued component of silvopastoral systems and the integration of pasture with trees requires that farmers act as a stabilizing force between the main components of the system, pasture and trees, and understanding the interactions between herbaceous vegetation, animals, and environmental components is a basis for future research and the design of silvopastoral systems (Sharrow, 1999).

1.2 Implications of multistrata systems

The benefits given by the incorporation of trees into farming systems have been widely listed (Wilson, 1981; Nair et al., 1984; Belsky et al., 1989; Shelton et al., 1991;

Cameron et al., 1991; Gutteridge, 1995; Belsky and Amudson, 1992; Belsky, 1992, 1994; Sanchez, 1995; Young, 1997). However, the literature in terms of farming systems, in which combinations of tree species of different stature play a central role or are an integral part of the system, is scarce. Mixed systems of different levels of structural complexity may be compared to forestry practices to explain why multistrata systems might be more productive in terms of output for a given energy input than open grasslands dominated by one or a few herbaceous species (Innis, 1997). As in a forest, agroforestry multistrata systems may provide soil protection against erosion, leaching and land slides (Michon, 1999). Multistrata systems could gradually build up soils by accumulating more biomass due to higher overall primary productivity occurring when several different types of plants are grown at once in a given area (Haggar and Ewel 1997; Innis, 1997).

Mixed species with different root systems, maturing at different times of the year, may use a higher proportion of the available water than one species (Innis, 1997). The same principle can be applied to soil nutrients. The presence of many roots in the soil may reduce nutrient losses via leaching (Young, 1997). Hence, nutrients can be extracted from root systems at different depths and densities, more so than in a monoculture, thus enhancing net primary productivity of the system (Hogberg, 1986).

The establishment of systems combining different tree species with diverse life forms may increase resources for animal production. Some species may have the ability to exploit resources that are unavailable to others, and also some species may be able to avoid defoliation and tolerate droughts. Animals therefore, may have more opportunities to directly access sources of feed and meet the nutrients needed for efficient productivity. In livestock systems, large grazing animals exert a number of influences on ecosystems. Light grazing can potentially increase biodiversity, but with heavier grazing, especially in drier conditions, some species or groups of species may be eliminated, thus decreasing diversity (Huenneke and Noble, 1996). In a multistrata silvopastoral system, trees occupying different strata create a variety of habitats and offer different products to the farming system, so biodiversity may be increased compared with a pasture only system (McAdam, 2000). Windbreak trees in pastures in

Costa Rica have been found to be important sites for regeneration of forest tree species and in habitat provision for migratory birds (Harvey, 2001).

The overall aim of the research presented here was to evaluate the role of trees and shrubs in seasonally dry pastures in Colombia in terms of their potential contribution to cattle diets and their interactive effect on associated pasture and animals (through resource use and amelioration of soil and microclimate).

1.3 Overview of thesis structure

Farmers' knowledge has often been ignored in the planning of livestock research in the Caribbean region of Colombia. Farmers' participation in research planning seems appropriate, since it is likely that they have a rationale for conducting farming practices in the way that they do and they often try to innovate themselves by identifying technologies that improve agricultural productivity. Therefore, the work reported here began with a participatory appraisal to ensure an appropriate understanding of the existing silvopastoral practices in the region and farmers attitudes towards the trees already in the landscape. The strategy used in this study involved a participatory survey amongst 54 farmers of the Caribbean region of Colombia (West margin of the Magdalena river), which is reported in Chapter 2.

The survey reported in Chapter 2 revealed that farmers retain and value a large number of different tree species within the region. It was, therefore, important to explore the effects of a range of native tree species on pasture production in order to evaluate their potential for integration within the farming systems of the region. In the context of seasonally dry pasture, benefits from trees need to be balanced against competitive effects, especially water use in the dry season. Research on water use and impact on understorey pasture productivity for three tree species was conducted in an experiment using single tree plots and is reported in Chapter 3.

Having established in the research reported in Chapters 2 and 3 that trees of various statures and species already exist in some pastures in the region and have different impacts upon pasture and make different contributions to farm productivity, a large multistrata field experiment was designed to explore the impact of different tree strata and their interactions with one another. This involved four strata: herbaceous pasture, leafy shrubs, arboreal (fruit producing) trees and timber trees in various combinations with grazing cattle. Three species relevant to the region were used in each of the tree strata. The establishment of the experiment and initial tree growth is reported in Chapter 4. Herbaceous and tree fodder biomass productivity of the various treatments are reported and compared in Chapter 5, while their nutritive value is explored in Chapter 6. Chapter 7 reports on the overall impact of the different treatments on the productivity of grazing cattle.

The final chapter (Chapter 8) summarises and discusses the findings of the research as a whole.

CHAPTER 2

CHARACTERIZATION OF MULTISTRATA SYSTEMS ON SEASONALLY DRY PASTURES IN THE CARIBBEAN REGION OF COLOMBIA

2.1 INTRODUCTION

Poor animal nutrition, caused by inadequate quantity and low quality of feed of tropical pastures in the dry season or cereal crop residues is a major cause of low livestock productivity in the tropics, especially in seasonally dry areas where there is a severe shortage of feed during the dry season. The aim of agroforestry systems is to mimic the favourable environmental influences of forest ecosystems and generate the exportable outputs achieved with agricultural systems (Knight et al., 2002). Retaining trees in pastures may improve their productivity and sustainability, especially in seasonally dry climates, through increased nutrient cycling and improvement of soil structure, the provision of dry season cattle fodder and the provision of shade for livestock which may reduce heat stress and increase feed intake (Humphreys, 1994; Young, 1997). Isolated trees on farmland are also now being recognised as important elements of fragmented forest canopy, contributing to the conservation of biodiversity in Latin America (Guevara et al., 1998).

The present research focuses on a 5.5 million ha area of the Caribbean region comprising seven geographically demarcated microregions. The region as a whole accounts for about 38% of national beef production and 43% of national milk production. The principal source of cattle feed is native (1.4 Mha) and improved (1.9 Mha) pasture. Productivity is constrained by an insufficient quantity of pasture, especially during the dry season.

In the agriculture and livestock research programme of Colombia, the interest in agroforestry systems is relatively recent and research is currently being initiated. While there has been little research to quantify their importance, it is evident that there already are appreciable numbers of trees on pastures. This research sought to document the role of these trees and shrubs, that have arisen either from planting or natural regeneration, together with farmers' attitudes towards the integration of trees into their farming systems and their knowledge about doing so.

The present chapter reports on a participatory rural appraisal that was carried out to characterise the present use of naturally regenerated or planted trees in pastures in the Caribbean Region of Colombia. The main objectives of this study were:

a) to document what farmers in the study area knew about the role of trees in pastures and their preferences for particular tree species, and
b) to characterise, in resource terms, the silvopastoral practices presently operating in the region and the prospects for their development.

2.2 RESEARCH STRUCTURE

2.2.1 Information abut the study area

The present research focuses on a 5.5 million ha area of the Caribbean region of Colombia (West of the Magdalena river) and includes the departments of Córdoba, Sucre, Bolívar and Atlántico (Figure 2.1). The region comprises seven geographically demarcated microregions (Table 2.1). Mean annual rainfall varies from 850-1500 mm mostly falling from April to November, and temperature fluctuates around 27°C (IDEAM, 1996). Productivity is constrained by an insufficient quantity of pasture especially during the dry season. Average stocking rate of animals in the region is around 1.5 animals ha^{-1} (CORPOICA, 1998).

Figure 2.1. Departments of the Caribbean region (West of Magdalena river).

2.2.2 Survey rationale

Given that the objective of the survey was to find out and document information from farmers about how trees were integrated in their farming systems, how they managed fodder tree and shrub species, and what they knew of the interactions between trees and pasture, structured interviews were used to collect information about farm size, enterprises on farms, management regimes in use, number of livestock, tree species growing on farmland, and tree species preference by type. The purpose of this survey was to obtain a reliable characterisation of how farmers use and perceive trees on pasture in some depth, rather than simply to inventory tree resources.

2.2.3 The selection of the study area

In selecting the microregions to serve as main study areas, the following criteria were adopted:

- Rainfall less than 2000 mm because trees are a more important fodder component in dry conditions

- Land not subjected to regular inundation, because this is likely to involve different tree species and pasture management than where sites are better drained, and, as explained above, tree fodder is of greater importance in dry conditions.

Four of the seven microregions complied with the above criteria. These were: Litoral, Golfo de Morrosquillo, Sabanas and Valle del Sinú. For each of these microregions, the following variables were calculated using information from the characterisation of farming systems in the Caribbean region (CORPOICA, 1998).

Proportion of the Caribbean region occupied,
% of farms less than 50 ha, 51 to 100 and >100 ha,
% of total area occupied by each agroecological zone (see Table 2.2.) and the proportion of each agroecological zone used grazing.

Table 2.1. Characteristics of the microregions of the Caribbean region (West of the Magdalena river).

Microregion	Soil type	Slope level	Vegetation	Rainfall mm	Climatic zones	Livestock systems
1 = Litoral	**Lo4-3a** = Orthic luvisols, fine textured and Miocene shales and sand-stones. Quaternary deposits; level to undulating. **Je18-3a** = Eutric Fluvisols, fine textured and alluvium; level to undulating. **I-Vp-E-c** = Lithosols-Pellic Vertisols-Rendzinas, Miocene sediments, level steeply dissected to mountainous.	0-25%	Drought-deciduous broad-leaved lowland (and submontane) woodland, degraded formations and cultivated land mosaic, mangrove and tropical tall flooded grassland.	1089	Tropical steppes	Milk
2 = Golfo de Morrosquillo	**Lo4-3a** = Orthic luvisols, fine textured and Miocene shales and sand-stones. Quaternary deposits; level to undulating. **Zg5-3a** = Gleyic solonchaks, fine textured and Quaternary marine and fluvio marine deposits, level to undulating.	3-25%	Mangrove, degraded formations and cultivated land mosaic and drought-deciduous broad-leaved lowland (and submontane) woodland.	1311	Tropical steppes	Milk and beef
3 = Sabanas	**I-Vp-Ec** = Lithosols-Pellic Vertisols-Rendzinas, Miocene sediments, level steeply dissected to mountainous. **Lo4-3a** = Orthic luvisols, fine textured and Miocene shales and sand-stones. Quaternary deposits; level to undulating.	0-25%	Degraded formations scrub cultivated land mosaic.	1334	Tropical savanna	Milk and beef
4 = Depresión Momposina	**Je18-3a** = Eutric Fluvisols, fome textured and alluvium; level to undulating. **Fo25-3b** = Orthic ferralsols, fine textured and Precambrian metamorphic rocks; level rolling to hilly. **I-Bd-Bh-c** = Lithosols, Dystric Cambisols, Humic Cambrisols, Jurassic and Cretaceous clastic and volcanic rocks, Precambrian and Paleozoic metamorphics, steeply dissected to mountainous.	1-15%	Very moist tropical ombrophilous lowland forest, degraded formations and cultivated land mosaic, tropical submontane ombrophilous forest and tropical tall flooded grassland.	2000	Tropical savanna Tropical rain forest Equatorial jungle	Cattle transhumance from Savannas and milk and beef (uplands)
5 = Valle del Sinú	**Lo4-3a** = Orthic luvisols, fine textured and miocene shales and sand-stones. Quaternary deposits; level to undulating **Ao1-3b** = Orthic Acrisols, fine textured and tertiary clastic rocks, some igneous outcrops, rolling to hilly. **Ao24-3b** = Orthic Acrisols, fine textured and old Palezoic metamorphics, basic and ultrabasic volcanics. Cretaceous and Tertiary clastics and alluvium, rolling to hilly. **Je18-3a** = Eutric Fluvisols, fine textured and alluvium; level to undulating.	3-15%	Very moist tropical ombrophilous lowland forest, degraded formations and cultivated land mosaic, tropical submontane ombrophilous forest and tropical tall flooded grassland	1308	Tropical rain forest	Milk and beef
6 = Bajo Cauca	**Ao24-3b** = Orthic Acrisols, fine textured and old Palezoic metamorphics, basic and ultrabasic volcanics. Cretaceous and terciary clastics and alluvium, rolling to hilly. **Je18-3a** = Eutric Fluvisols, fine textured and alluvium; level to undulating.	3-50%	Very moist tropical ombrophilous lowland forest and tropical evergreen seasonal lowland forest	2703	Tropical rain forest Equatorial jungle	Beef
7 = Uraba Norte	**Zg5-3a** = Gleyic solonchaks, fine textured and quaternary marine and fluvio marine deposits, level to ondulating. Je18-3a = Eutric Fluvisols, fine textured and alluvium; level to undulating. **Lo4-3a** = Orthic luvisols, fine textured and miocene shales and sand-stones. Quaternary deposits; level to undulating. **Ao24-3b** = Orthic Acrisols, fine textured and old Palezoic metamorphics, basic and ultrabasic volcanics. Cretaceous and Tertiary clastics and alluvium, rolling to hilly.	5-25%	Moist tropical ombrophilous lowland forest. Rainfall is around	1000	Tropical savanna	Beef

Source: FAO-UNESCO, (1971); Anon, (1969); UNESCO, (1981), CORPOICA (1998), IDEAM (1996)

According to the Geographic Institute "Agustin Codazi", that classfies land in Colombia on the basis of its agricultural capability, there were 19 agroecological zones occurring in the microregions selected for the survey (ICA-IGAG, 1986), (Table 2.2; Appendix 2.1).

An index of grazing importance (IGI) was calculated for each agroecological zone as follows:

$$IGI = \frac{AT}{100}$$

Where:
IGI = Index of grazing importance (0-100)
A = % area of land grazed in each zone
T = % of total microregion land occupied by zone

Based on the IGI (Table 2.2) and the suitability of the soils for each agroecological zone, two zones were selected: these were Cu and Cj. The criteria for selecting these two agroecological zones were that :

- IGI not less than 8%;
- Soils not to have high aluminium saturation levels, because the main constraints in these ecosystems are toxicity, low nutrient reserves and weed encroachment. Therefore, trees suitable for such conditions are likely to have different ecology and management than in other areas;
- Land not to be flooded at any time of the year, once again because, trees are likely to be less important on pasture in wetter areas
- Contrasting soil fertility among the selected zones to may allow a comparison of the role of trees on soils of different fertility.

The sample for soil fertility comparisons was focused in Sabanas and Valle del Sinú microregions.

Table 2.2. Calculated values of each variable of the four selected microregions of the Caribbean region (West of the Magdalena river).

	Microregions											
Variables	Litoral			Golfo de Morrosquillo			Sabanas			Valle del Sinú		
Total area microregion (ha)	665 362			215 628			1 674 959			1 033 144		
% of total area of region	12.1			4.0			30.4			18.7		
% farms <50 ha	27.3			18.2			30.9			18.7		
% farms 50-100 ha	24.7			32.7			24.8			21.5		
% farms >100 ha	40.4			46.1			40.9			50.3		
% area occupied by cattle production	56.5			77.6			67.8			50.4		
% area in improved pasture	45.6			56.8			32.2			35.9		
% area in native pasture	10.9			20.9			35.7			14.5		
Agroecological zone (%)	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
C	2.6	19.1	0.5	7.1	34.2	2.4	0.3	93.1	0.3	-	-	-
Cf	6.3	57.0	3.6	-	-	-	-	-	-	-	-	-
Cj	**12.7**	**72.8**	**9.2**	**12.0**	**82.5**	**9.9**	**14.4**	**61.7**	**8.9**	**8.1**	**81.4**	**6.6**
Cn	20.8	61.2	12.8	41.7	89.8	37.4	2.6	66.0	1.7	0.6	76.1	0.5
Co	-	-	-	-	-	-	14.5	67.0	9.7	-	-	-
Cu	**29.3**	**68.4**	**20.0**	**21.1**	**78.5**	**16.6**	**55.6**	**69.1**	**38.5**	**13.8**	**63.1**	**80.7**
Cv	13.1	40.3	5.3	15.6	59.9	9.3	7.04	60.3	4.4	0.2	84.6	0.1
Cx	1.0	88.1	0.9	0.9	84.0	0.7	0.04	-	-	0.1	-	-
E	0.3	27.2	0.1	-	-	-	-	-	-	-	-	-
Kb	-	-	-	-	-	-	0.9	61.2	0.6	12.0	91.0	10.9
Kr	-	-	-	-	-	-	1.20	94.2	1.1	-	-	-
Ku	-	-	-	-	-	-	1.34	73.0	0.98	28.1	17.9	5.1
Kv	-	-	-	-	-	-	-	-	-	17.4	23.6	4.1
Mk	-	-	-	-	-	-	-	-	-	1.9	-	-
W	10.9	20.8	2.3	1.6	70.9	1.1	2.5	50.6	1.4	17.5	80.7	14.2

1 = % of each agroecological zone in relation to total land area of microregion region
2 = % of grazed area in each agroecological zone
3 = IGI (1 x 2)

2.2.4 Farm selection

Using the records from ICA-USDA[1] for each municipality and their corresponding villages, either allocated in Cj or Cu agroecological zones, a stratified random sample of 54 farms was selected. The soils and microregion maps were overlapped to corroborate the allocation of each farm in either Cj or Cu agroecological zone (Figure 2.2). Farm size for the sampling procedure was according to the same classes used by ICA-USDA technicians in the foot-and-mouth control programme, and CORPOICA for the characterisation of farming systems. The number of farms selected for each agroecological zone in each microregion is given in Table 2.3.

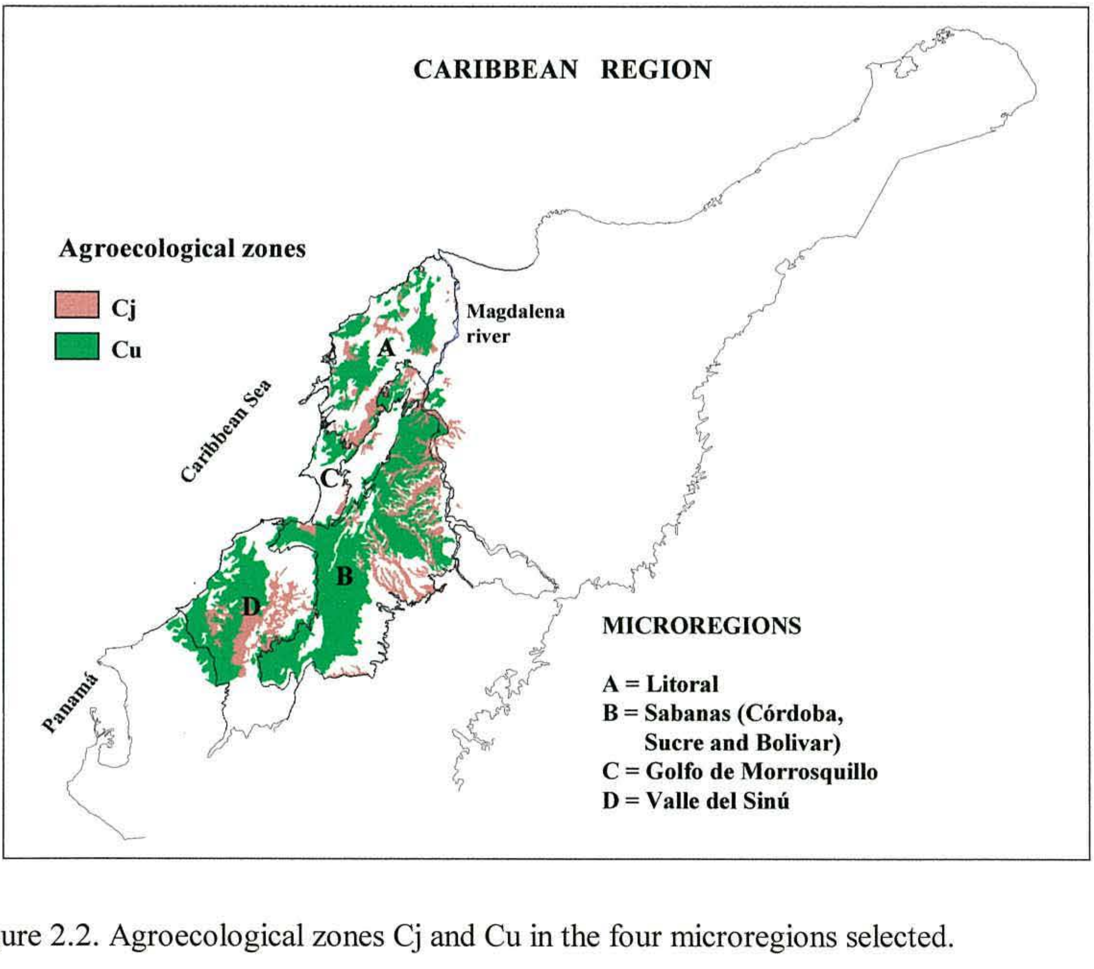

Figure 2.2. Agroecological zones Cj and Cu in the four microregions selected.

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[1] ICA: Instituto Colombiano Agropecuario. USDA: United State department of Agriculture.

Table 2.3. Number of farms selected for each microregion in each agroecolegical zone.

Microregion	Farm size (ha)	Agroecological Zone Cj	Cu	Total
Litoral	<50	-	3	3
	50-100	-	3	3
	>100	-	3	3
Golfo de Morrosquillo	<50	-	3	3
	50-100	-	3	3
	>100	-	3	3
Sabanas	<50	3	3	6
	50-100	3	3	6
	>100	3	3	6
Valle del Sinú	<50	3	3	6
	50-100	3	3	6
	>100	3	3	6
TOTAL		18	36	54

2.2.5 Interviews

Specific and quantitative information about farm size, farm enterprises, management regimes, number of livestock, tree species on farmland and their uses was collected during the interviews. The interviews were conducted in Spanish in an extended conversation either with the owner or the stockman and lasted from one to two hours. Farmers used local names during the interview, and later the trees were botanically identified in the field. The questionnaire used for collecting the information by interviewers is reproduced in Appendix 2.2. An oral structured interview, an estimated tree inventory and a sketch-map of the land use was carried out on each farm. Information about the numbers and specific uses of trees was also provided by the farmers. The sketch-map was drawn walking the farm and corroborating each sketch-map with each farmer. In a few cases the sketch-map was drawn using a farm plan provided by the farmers. The sketch-maps were used to allocate the distribution of the trees in each farm.

2.2.6 Data analysis

Data on microregion, agroecological zone, farm area, estimated tree density, area used by livestock, stocking rate, percentage of land with trees and percentage of trees used for timber, fodder, shading, live fences, fruits and palms were analysed using the cluster procedure in SAS (SAS, 1989). Four clusters were identified. Chi-square tests for goodness of fit were used on species presence to investigate whether the occurrence of individual species were independent of clusters (data from Cluster 3 and 4 were amalgamated for this analysis because of the low number of observations in Cluster 3). Correlation and regression analysis were conducted in SAS to ascertain the relationship between different types of tree uses across farms within clusters.

2.3 RESULTS

2.3.1 General characteristics of farms

Cluster analysis revealed four characteristic patterns of farms (Table 2.4), with the mean area of farmland with trees on it ranging from 26% to 69%, and the mean tree density on that land varying from less than 3 trees ha^{-1} to over 50 trees ha^{-1}. Farms in Cluster 3, where the majority of the farms were in areas of low to moderate fertility, had the highest tree density as well as the highest proportion of farmland incorporating trees (over two-thirds). Farms in Cluster 4 also had tree cover on over half their land area but at only fifth of the tree density of those in Cluster 3. The majority of farms in Cluster 3 and 4 were not only on land of moderate fertility, but between a quarter and a third of them were also located in the Litoral microregion, that has only just over 1000 mm of annual rainfall (Figure 2.3). Farms in Cluster 2, that had the lowest tree density, were predominantly on soils of higher fertility and all dedicated entirely to beef production, without a dairy component. The farms in Cluster 1 were similar to those in Clusters 3 and 4, in being dual purpose and predominantly on low fertility soils but had much higher animal stocking rates and correspondingly fewer trees.

Table 2.4. Characteristics of farms allocated to four clusters in the Caribbean region of Colombia.

	Microregion [1/]				Land capability		Farm type		Stocking rate	Tree density	% of land with trees
Cluster	A	B	C	D	Cu	Cj	Dual Purpose	Beef			
			%		%	%	%	%	animals ha^{-1}	trees ha^{-1}	%
1 (n = 17)	6	12	47	35	71	29	100	-	2.3 (0.23)	4.7 (0.99)	25.7 (6.24)
2 (n = 12)	0	17	25	58	33	67	-	100	1.7 (0.15)	2.6 (0.68)	43.3 (6.31)
3 (n = 8)	25	38	25	12	75	25	100	-	1.0 (0.08)	53.1 (24.3)	68.8 (6.32)
4 (n = 17)	35	12	29	24	82	18	94	6	1.3 (0.14)	10.8 (2.55)	56.2 (6.77)

[1/] A = Litoral, B = Golfo de Morrosquillo, C = Sabanas, D = Valle del Sinu

Cu = low or moderate fertility, slopes up to 25%, more suitable for grazing than cropping; Cj = high fertility, slopes <7% suitable for cropping

Standard errors are presented in parentheses

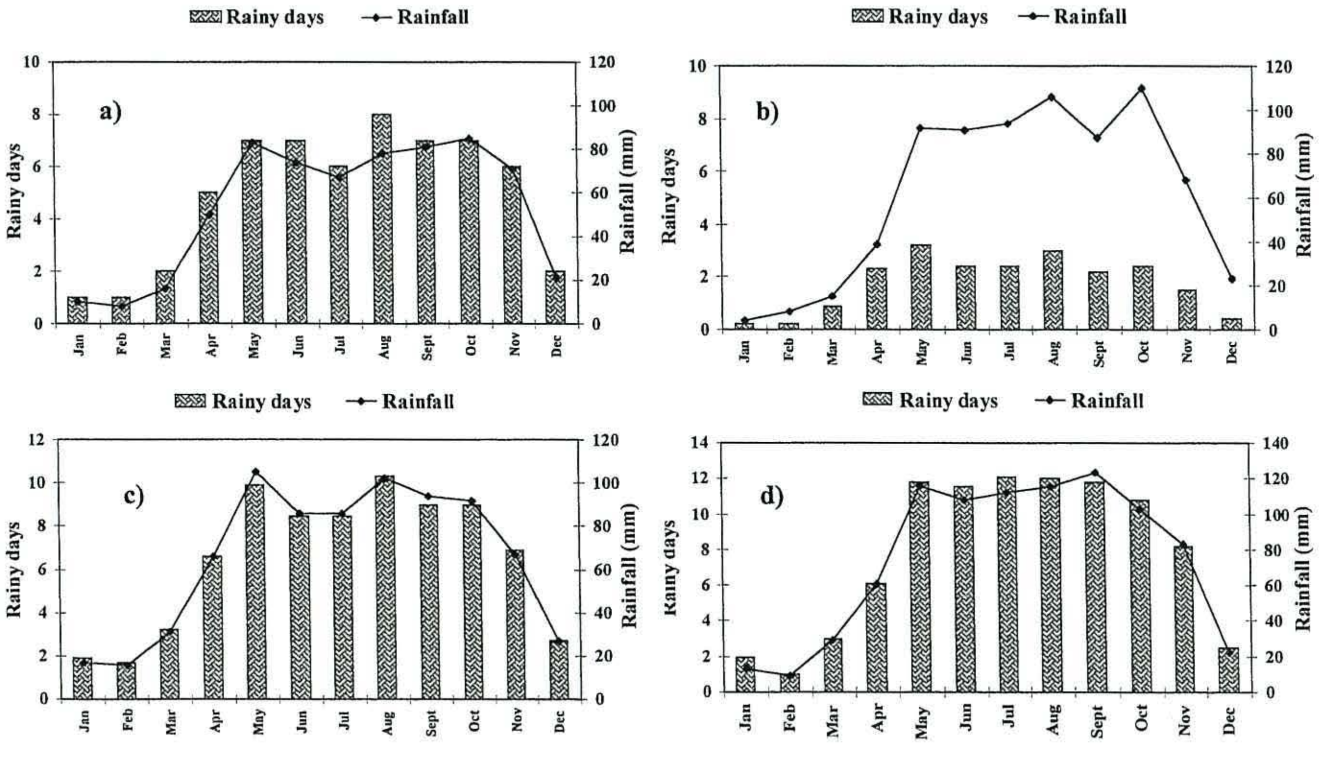


Figure 2.3. Mean monthly and rainy days from 1992 to 1996 a) Litoral, b) Golfo de Morrosquillo, c) Sabanas and d) Valle del Sinú microregions (IDEAM, 1996).

2.3.2 Preferences for different types of trees

In all, 96 different tree species were present on the 54 farms (list available in Appendix 2.3). There was no significant association between the occurrence of individual timber or fodder species and farm type (cluster). Most of the trees on farms (between 70% and 90% according to cluster) were primarily used for timber or fodder. While timber trees were more numerous than fodder trees for farms in Clusters 2 and 3, there were similar numbers of timber and fodder trees in Cluster 1 but far more fodder than timber trees in Cluster 4 (Figure 2.4). In Clusters 2 and 4, there was a negative relationship between timber and fodder trees with farms with a high percentage of timber trees having fewer fodder trees ($P<0.001$).

Twelve timber species were commonly found on pasture, with frequency varying by cluster, although *Tabebuia rosea* occurred on over two-thirds of farms and was by far the most common in all clusters. *Albizia caribea* and *Sterculia apelata* were also common in all clusters, found on between a quarter and half of the farms (Figure 2.5). Most farmers stated that there were valuable timber species they wanted to have more of on their farms. The most desirable were: *Pachira quinata* (syn: *Bombacopsis quinata*), because of its highly prized wood for construction and manufacture of furniture; *Swietenia macrophylla* and *Aspidosperma polyneuron* because these are species on the verge of extinction in Colombia and so their wood is in great demand and their timber fetches a high price.

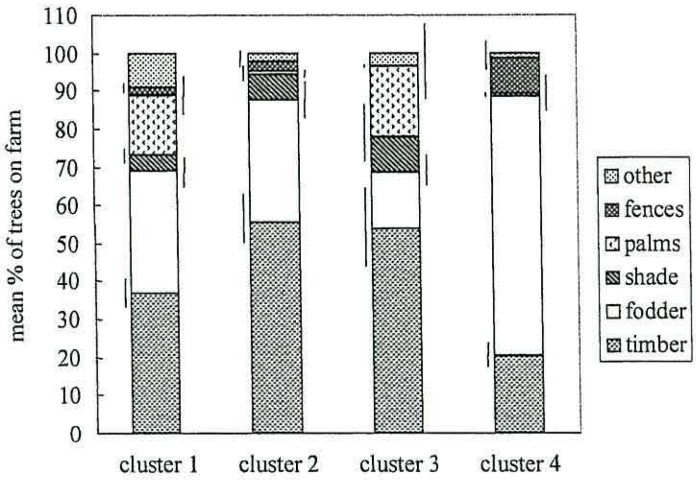


Figure 2.4. Distribution of trees with different principal uses on farms in the Caribbean region of Colombia. Farms were divided into four clusters on the basis of various land type and use factors (Table 2.4). Vertical bars show standard errors.

Whilst some farms had strategies for maintaining livestock productivity in the dry season other than using trees, such as transhumance, the use of feed supplements (crop residues, molasses or hay) or selling animals, 83% of farmers said that during periods of pasture shortage, they were highly dependent on fodder trees, especially on those which produce pods such as *Albizia saman* and *Cassia grandis*, or fruits such as *Guazuma ulmifolia* and *Crescentia cujete* (Figure 2.6).

Two species were commonly found to be used as live fences, *Gliricidia sepium* and *Spondias mombin*, but because each fence was included as a single unit in the inventory, rather than individual stems being counted, their importance as a resource is understated here. Palms, mainly *Sabal mauritiaeformis*, which is used both in roof construction and production of an edible, celery-like, heart-of-palm, played an important role on some farms in Clusters 1 and 3 (Figure 2.4), mainly on smaller farms (less than 100 ha). The correlation analysis showed a negative relationship between presence of palms and either fodder or timber trees ($P<0.01$) for farms in Cluster 1 with those farms that had a large number of palms on their pasture having correspondingly fewer timber or fodder species.

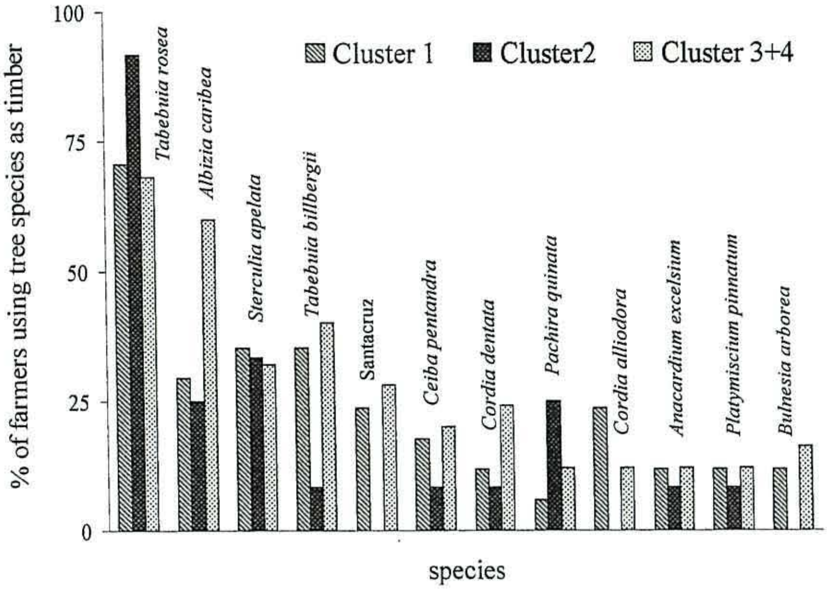


Figure 2.5. Species most frequently named by farmers four use as timber in the Caribbean region of Colombia. (Santacruz not identified).

Only a few trees were retained principally to provide shade for cattle (Figure 2.4) but the majority of farmers said that shade from all trees, whatever their principal productive use, was the most important reason for having trees on their farms at all, indicating the inherent multipurpose nature of trees in this silvopastoral context. In fact, few species were used for only one purpose; most were thought to make multiple contributions to the farm albeit of varying importance in different aspects. Many trees provided shade, leaves and pods for feeding animals, timber, firewood, and poles and could be used in live fences. *Gliricidia sepium, Guazuma ulmifolia* and *Albizia saman* were particularly valued as multipurpose species in all clusters.

Farmers also mentioned that there were trees they did not want to have on their farms for combinations of the following reasons: they produced heavy shade, had large crowns, were thorny, propagated rapidly or were neither useful for fodder nor timber. *Lecythis minor, Sapium aucuparium*, *Pithecellobium lanceolatus* and *Ficus carica* were commonly mentioned in all clusters as species that farmers avoided.

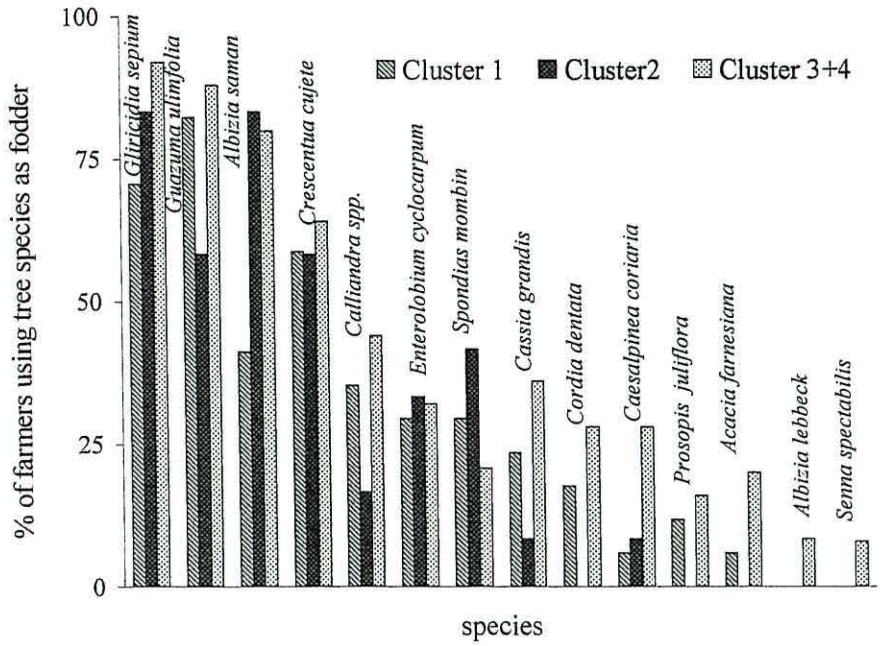


Figure 2.6. Species most frequently named by farmers for use as fodder in the Caribbean region of Colombia.

2.3.3 Tree – animal interactions

Some fodder tree species were found only in some clusters, for example, *Senna spectabilis* and *Albizia lebbeck* were found only in the Litoral microregion and so were encountered only in Clusters 3 and 4 (Figure 2.6). However, there were a number of fodder species which were common in most clusters such as *Guazuma ulmifolia, Gliricidia sepium, Albizia saman, Crescentia cujete, Calliandra spp., Spondias mombin, Enterolobium cyclocarpum* and *Cassia grandis* (Figure 2.6).

All farmers were able to state which fodders they thought cattle preferred (Figure 2.7). Two species were highly ranked in all clusters, *Guazuma ulmifolia* which was thought most preferred by cattle in Clusters 1, 3 and 4 and ranked second in Cluster 2 and *Albizia saman,* ranked highest in Cluster 2 and second in the other clusters. *Crescentia cujete* was mentioned as one of the most useful fodder trees because it could be managed either as a shrub (for leaves) or an arboreal tree (for fruit). As a browse tolerant shrub, it remains green during the dry season and produces fruits that can be used as an alternative feed when pasture resources are limited. Farmers said that fodder trees not only sustained the physical condition of cattle during dry periods but, mixed with crop residues, enabled higher milk production. On most farms there was, nevertheless, a constraint throughout the dry season because of the short period that tree pods are available and the lack of other sources of protein necessary to maintain an appropriate ratio of protein to energy in animal diets. Availability of crop residues varied and in some areas there was not enough to be used for animal consumption.

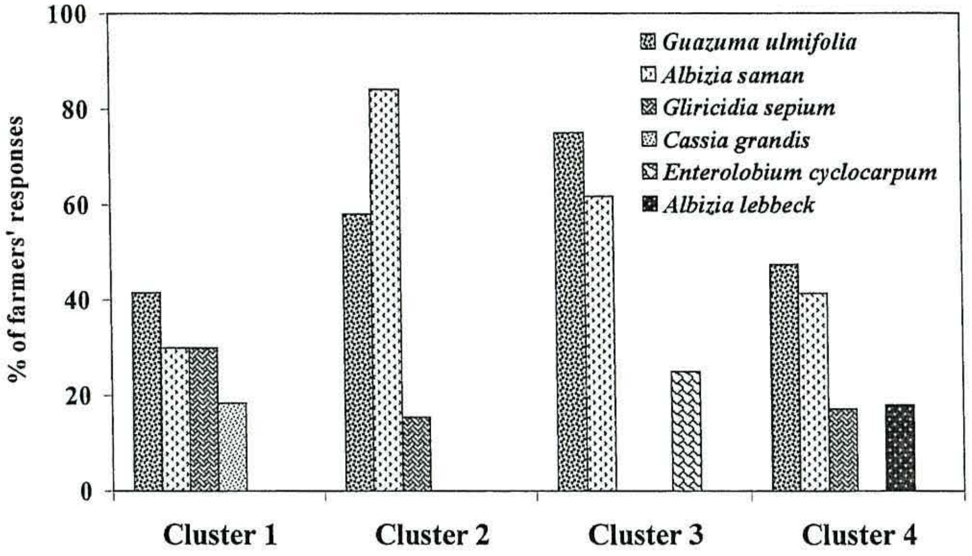


Figure 2.7. Fodder species that farmers said were preferred by cows. Responses are expressed as percentages of the total number of farmers surveyed (most farmers named more than one species). Only species mentioned by three or more farmers are shown.

2.3.4 Effects of trees on pasture

There were inconsistencies in the information obtained from farmers and stockmen about shade tolerance of grass species. However, *Dichanthium aristatum, Panicum maximum, Brachiaria mutica* and *Cynodon nemfluensis* were classified as shade tolerant in all clusters and *Brachiaria brizantha* and *Hyparrhenia rufa* were consistently classified by farmers in Cluster 1 as being sensitive to shade. In all clusters, the majority of farmers said that trees affected pasture. The main reasons given for trees having a detrimental effect on pasture production were:

a) dense crowns which produce heavy shade,

b) high tree density, and
c) trampling and soil compaction in the area around the trees.

The negative effects of trees on pasture were manifest as a reduction in grass growth where the shade was very dense and an increase in weeds, especially in those areas where animals rested for a long time. According to some farmers, trees can also influence grass growth positively, because some grass species grow better under the cooler conditions under tree crowns.

2.3.5 Tree retention and planting

The majority of farmers in Clusters 1, 2 and 4 (71%, 75% and 83% respectively) and half of the farmers in Cluster 3 planted trees. All farmers in Clusters 1 and 2, almost all (94%) in Cluster 4 and 80% in Cluster 3 said that they encouraged natural regeneration of trees. The main constraints to planting trees in pastures were the cost of protecting young trees from cattle damage and loss of young trees during the dry season due to desiccation.

The most commonly cited reasons for planting and/or encouraging natural regeneration of trees on farms were: the production of pods to serve as a cattle feed during the dry season, shade for cattle, timber, firewood and poles for fencing. Additionally farmers claimed that the presence of trees had multiple benefits for the environment such as control of erosion, increasing rainfall, and the protection of streams and whole watersheds.

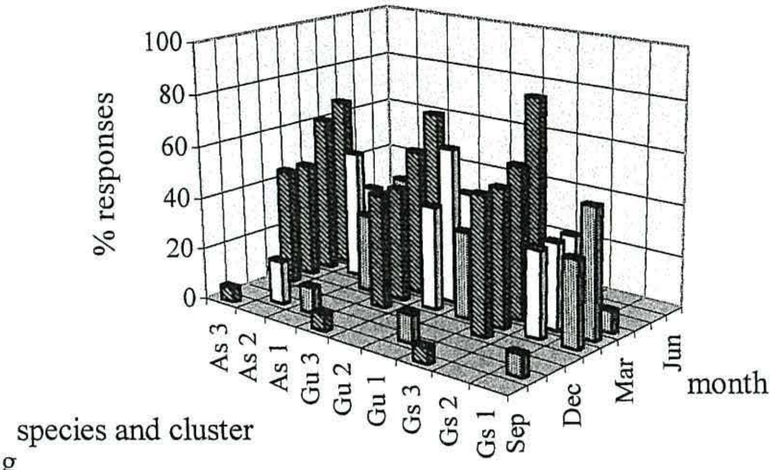
2.3.6 Phenology

Phenology of trees in terms of when they supply fodder from leaves and pods or fruits and provide shade is clearly of critical importance to the role that different species can play within silvopastoral practices in the region and for the design of appropriate mixtures of species. There was, however, considerable variability in farmers' knowledge about the phenology of some of the most commonly utilised species, both within and between clusters (Figure 2.8). Some of this variation may reflect genuine differences in the timing of processes in different microregions (for example rainfall decreases and the length of the dry season increases with distance from the coast) and in how trees are managed (*Gliricidia sepium*, for example, is often lopped when used as a live fence which may alter phenology, depending on when the lopping is done). However, only a proportion of farmers were confident enough to state information about phenology and there is considerable residual contradiction in their responses, even after taking the likely effects of environmental variability into account. This indicates a critical lack of information for design of silvopastoral systems in the region amongst farmers.

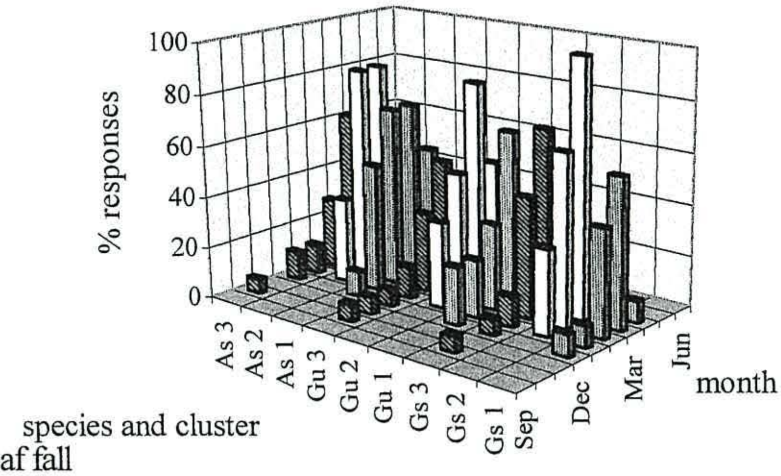
2.3.7 Dry season effects on animal production

Some farmers (63%) were able to quantify the losses of milk production from the wet season to the dry season. There was no correlation between the decrease of milk production and farm type (cluster) or percentage of fodder tree in each cluster. However, milk yield losses were higher in Clusters 1 and 4 (71.94%±7.16 and 73.40%±4.29 respectively) than in Clusters 2 and 3 (48.01%±13.51 and 49.16%±8.44 respectively). Farmers from Cluster 2 dedicated entirely to beef production quantified the losses in beef production as well. From the wet to the dry season, the losses in beef production were in the order of 54.24%±9.5. This suggests the need farmers have to develop appropriate technologies to improve the unsustained and inefficient existing production systems in the Caribbean region.

a) flowering



b) fruiting



c) leaf fall

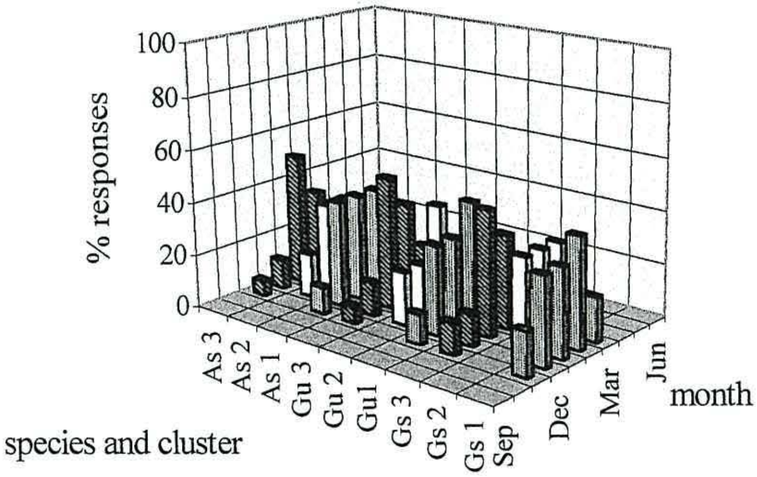


Figure 2.8. Phenology of a) flowering b) fruiting and c) leaf fall in *Gliricidia sepium, Guazuma ulmifolia* and *Albizia saman*. Y-axis shows the percentage of farmers who stated that the process concerned occurred in a particular month. Key: Gs1 – responses of farmers in Cluster 1 for *G. sepium*, Gs2 – responses of farmers in Cluster 2 for *G. sepium*, etc. Of 17 farmers surveyed in cluster 1, 12 responded with respect to *G. sepium*, 9 for *G. ulmifolia* and 10 *A. saman*, for cluster 2 the corresponding figures were 3, 5 and 6 out of 12 and for clusters 3 and 4, 17, 16 and 18 out of 25.

2.4 DISCUSSION

Hypothesis

Farmers's knowledge of fodder trees in the Caribbean region would be important in selecting species in order to develop an evaluation of forage potential trees and shrubs in the silvopastoral systems in the Caribbean region. These species may indicate the most appropriate attributes of the fodder tree species for integration in their farming systems.

The study demonstrated that farmers in the study area of the Caribbean region have a knowledge of different tree species that exist in their farming systems which they manage on the basis of local knowledge of tree-pasture interactions and an understanding of tree attributes.

Cluster analysis revealed a multistrata system with four characteristic patterns of tree use, with farms differing in both tree density and use. In all 96, tree species were found within pastures. The degree and pattern of utilization of tree species appeared to be influenced by the dominant livestock system. Farmers dedicated entirely to beef production without a dairy component were more inclined to grow timber trees, while farmers that have included a dairy component preferred to have fodder tree species and most interest was shown in tree species that produce pods during the dry season. Even though fodder and timber species were the most preferred by farmers, the majority of farmers agreed that the provision of shade, whatever the principal productive use of trees might be, was the primary reason to leave trees in their pastures. All farmers showed a positive attitude towards to keeping trees in their farming systems and they had a clear concept of multipurpose trees, and most of the species were classified by them as having more than one use (timber, fodder, leaves production, firewood and fence posts).

Farmers not only listed the benefits tree species provide to improve or to alleviate difficulties of their farming systems, such as provision of fodder and pods to feed animals during times of pasture scarcity, or shade which reduces animal stress, but they were able to identify a variety of reasons why having trees on their farms was beneficial for the environments. Harvey and Haber (1998) and Thapa et al. (1995) have listed a number of examples showing how much farmers know about the role of trees in relation in the environment. Farmers of the Caribbean region mentioned that trees play an important role in controlling erosion, increasing rainfall and protection of streams and watercourses. Farmers in Costa Rica cited similar responses and additionally mentioned benefits of wildlife protection and personal enjoyment (Harvey and Haber, 1998). In Nepal farmers did not grow trees they have identified as species that increase soil erosion (Thapa et al. 1995).

Most of the farmers from the Caribbean region showed a sophisticated understanding of what tree species they allow to grow in their pastures, and what species they do not want to have in their farms for a combination of negative reasons such as heavy shade, large crowns, rapid spread, which affect pasture productivity, or they were thorny which cause problems to the animals, or were neither useful for fodder or timber. Therefore, *Lecythis minor*, *Sapium aucuparium*, *Pithecellobium lanceolatus* and *Ficus carica* are species that farmers mentioned were to be avoided.

Although there were some inconsistencies in farmers' knowledge about shade tolerance of grass species, some grasses they mentioned as shade tolerant, have been reported in the literature as species tolerant to shade. Such is the case of *Panicum maximum*, which is reported in the literature to be highly tolerant to shade (Wong et al., 1985; Kennard and Walker, 1973; Bosh and van Wyk, 1980), and *Cynodon nemfluensis,* which produced higher dry matter (6.8 t ha^{-1}) in a silvopastoral system with *Erytrina poepigiana* than in open sunlight pasture (4.4 t ha^{-1}) (Bustamante, 1998).

The reasons farmers gave for trees having a detrimental effect on pasture concur with scientific ideas about this. Dense crowns which produce heavy shade are thought to reduce understorey plant productivity through competition for light and several studies looking at this have been conducted (Eriksen and Whitney, 1981; Kang et al., 1981; Isichei and Muoghalu, 1992). However, the exact conditions altering productivity under tree crowns relative to open grassland are still unknown. High tree density, another reason given by farmers for reduced pasture growth can reduce understorey productivity by competition between trees and herbs for water and nutrients (Somarriba, 1988; Jackson et al., 1990; Walker et al., 1986). Weltzin and Coughenour (1990) found that tree shade is sought by wild and domestic herbivores and it is likely that understorey soil is disturbed by trampling and herbivore urine and dung deposition. Trampling and soil compaction in the area around trees was mentioned farmers as a reason to effect pasture productivity.

Farmers mentioned that trees can also influence grass growth positively, because some grass species grow better under the cooler conditions under tree crowns. Harvey and Haber (1998), in a survey of 24 dairy farms in Costa Rica, found that one of the reasons given by farmers for having trees in their pastures was that the grass remained greener for longer during the dry season because the trees shaded the grass and prevented it from being desiccated by the sun. Similar observations have been made in Africa where productivity of *Pennisetum pedicillatum* under trees was about twice that of open areas in the Sahel, and evapotranspiration of *Panicum maximum* in Botswana was reduced by 50-70% under shade and hence it remained green for six weeks longer into the dry season than when unshaded (Houérou, 1978). Reduction of evaporation from bare soil through shading by tree crowns has recently been identified as an important mechanism for improving water use efficiency of arable crops in dry climates (Wallace and Batchelor, 1997). Belsky et al. (1993a) found higher herbaceous-layer production at high-rainfall and low-rainfall sites in Africa, under tree canopies than in open grasslands, and similar reductions in solar radiation by tree canopies in both sites. Tree canopies reduced radiation by approximately 45% over the entire day and by 53-65% during the hours of direct shade.

All farmers showed plenty of evidence of their knowledge to identify tree species most preferred by cattle. The outstanding tree species of these silvopastoral systems were *Guazuma ulmifolia* and *Albizia saman*, which grow very well in the Caribbean region and produce large quantities of fruits and pods, which mature and drop during the dry season. In general most farmers were receptive to the idea of increasing the number of trees in their farming systems. Individual farmers differed in their reasons to plant trees, some wishing to have more timber trees and others desiring more fodder trees, especially those that produce pods during the dry season.

The results of this study evidenced and confirmed the importance of incorporating an understanding of farmers' knowledge to conduct cooperative research with farmers on technical issued by letting farmers participate in and, in some cases, by involving farmers in experimental strategies (Nitis, 1987). In the process of agricultural development in Colombia, almost no attention has been given to farmers as active and empirical experimenters in their own right. Farmers have been seen for many years as adopters of introduced technologies, mainly from the outside. It is crucial for the recent agroforestry research, which is currently being initiated in Colombia to understand that agroforestry is generally seeking to address problems experienced by farmers in a holistic manner (Sinclair and Walker 1999). The evidence of the farmers' local knowledge from the Caribbean region suggests that there is a prosper community parallel to the community of formal agricultural researchers and as suggested by Sinclair and Walker (1999), researchers can learn from local knowledge both about farmer practice and the ecological processes operating in farmers' fields to be able to design and generate technologies which farmers could easily adopt.

From the results of the survey it is documented that there is a need for the farmers to develop appropriate technologies, which can contribute towards alleviating, constraints in animal production, especially during periods when herbaceous grasses and legumes are scarce. Both farmers dedicated to beef production and farmers with a dairy component are affected by the lack of appropriate technologies to avoid losses during the dry season. It is clear from the survey that the multiple strata and species found in the silvopastoral practices of the region are fundamental to their functionality. Trees of larger stature provide shade and produce timber, the most important fodder trees are those of medium stature that produce fruits or pods in the dry season (but will also provide some shade), while some species can be managed as browse tolerant shrubs producing green leaf fodder throughout the year and especially during the dry season when pasture productivity and quality is low. The relative importance of these different roles of trees, related to the strata they occupy, has not been taken into account in the design of silvopastoral systems in Colombia. To investigate this, a multistrata experiment to evaluate the impact of different levels of tree and shrub diversity on the sustainability of pasture and cattle production has been set up based on the results of the present survey. The overall aim is to evaluate the role of trees and shrubs of different stature in terms of their contribution to cattle diets, their interactive effect on associated pasture and animals (through resource use and amelioration of soil and microclimate) and their potential to produce both timber and fuelwood (see Figure 4.3 in Chapter 4). The experiment will be used for a blend of system level measurement of productivity (for example, milk production and tree growth) and process-based research to explain differences in system performance (for example, comparison of stress levels in cattle with different levels of shade and quantification of nutritive value and feed intake of different vegetation). The survey results changed researcher's perspective on which species to include in the multistrata experiment. Therefore, species were chosen that are either already commonly used or valued by farmers, as in the case of *Pachira quinata* and *Swietenia macrophylla*, farmers would like to have more of them. *Leucaena leucocephala* was included because it has been successfully used as a shrub species in experimental trials in the region. A critical feature of the experiment is the possibility to evaluate the relative importance of fodder from leaves as opposed to pods and fruits and the relative importance of shade and fodder supply, as well as their interaction.

CHAPTER 3

TREE PASTURE PRODUCTIVITY AND RESOURCE USE ON SINGLE TREE PLOTS

3.1 INTRODUCTION

In agroforestry systems the effects of trees on the understorey environment are often as or more important than the productivity of the trees themselves. Previous research on forages in the Caribbean region of Colombia has concentrated on nutritional analysis of herbaceous species, despite trees and shrubs being potentially important elements of livestock diets (Cajas-Girón and Sinclair, 2001). In considering woody perennials as fodder species, the trade off between the fodder they supply and their competitive effect on pasture requires investigation (Aletor and Omodara, 1994). In this chapter the effects of a wide range of native tree species on pasture production and composition are measured. Specific attention is given to competition for water, which limits plant growth and fodder availability in the dry season, and may be affected by tree defoliation caused by browsing or pruning.

Competition in the present context principally involves resource capture, where trees capture light, water or nutrients that would otherwise be available to understorey plants (Ong and Huxley, 1996; Cannell et al., 1996). For cattle production systems in the Caribbean region of Colombia, water is the most limiting resource for a critical part of the year. In the dry season, low water availability results both in low biomass productivity of pasture (Cajas et al., 1985; Murgueito, 1990) and low digestibility and nutrient content of the biomass that is available (Minson, 1990; Humphreys, 1994). Overall competition is evident in the productivity of components but may be the net result of both positive and negative interactive effects (Anderson and Sinclair, 1993). Tree shade, for example, may be beneficial in reducing evaporative demand in hot, dry environments (Wallace and Batchelor, 1997) while also reducing light levels and hence potential productivity of the understorey. Understanding interactive effects is important for management purposes, since they may be influenced by management interventions such as species choice, planting density and animal stocking rates (Sinclair et al., 2000). In silvopastoral systems, animals defoliate plants when grazing and browsing which may alter the competitive balance amongst species. Trees may respond to defoliation by altering their transpiration and carbon allocation (Singh and Thompson, 1995), causing complex changes in shade levels, rooting behaviour and water uptake that may vary amongst species (Jones et al., 1998).

The overall objective of this research was to compare fodder tree species that may be used in seasonally dry pasture in Colombia in terms of their impact on pasture production and composition. This involved exploring the following two hypotheses.

1. The presence of tree species differentially affects understorey pasture productivity

2. Competition for water amongst trees and pasture depends on tree species and different tree species respond differently when defoliated.

Information about effects of trees on pasture, in combination with information on the fodder they supply, can help in selecting appropriate species for integration on livestock farms.

3.2 METHODOLOGY

3.2.1 Field site

The field site was situated within the Turipaná Research Station, Cereté, Córdoba, Colombia (8°51'N, 75°49'W, at an altitude of 18 m above sea level), a regional centre of CORPOICA, the national agricultural research institution of Colombia. Mean annual rainfall recorded at the site between 1995 and 1999 was 1380 mm (standard deviation 183 mm). The driest period occurs between December and March (<10% mean annual rainfall), while the wettest period is from May to October (>80% mean annual rainfall). The area is characterized by deep soils having a high clay content and water holding capacity (described as Orthic luvisols and acrisols in the Soil Map of the World (FAO-UNESCO, 1971). If poorly drained, they are prone to surface inundation following heavy rainfall.

The plot had previously been grazed during the 1970s and 1980s, and later abandoned as pasture became dominated by *Paspalum fasciculatum*, a grass of low palatability. To recover the pasture, it was sown with *Mucuna deeringiana* in May 1994 and grazed on a rotational basis. Tree seedlings were planted in October 1995. Initially, as the trees established, cattle were excluded from the plot and pasture cut mechanically.

3.2.2 Layout and experimental design

The experimental plot (3.4 ha) was planted at an overall density of 82 trees ha^{-1}, with eleven tree species occurring in a randomised sequence, planted in a triangular arrangement, with trees at 10.6 m spacing within rows, that were 5.3 m apart and centrally offset so that the minimum distance between trees was 7.5 m (Figure 3.1).

Trees were treated as single tree plots with 24 replicates of each species but there was no control without trees because control areas within the field could eventually have been influenced by neighbouring trees. In order to take account of variation across the field, the experimental area was divided into two blocks (referred to as badly drained and well drained respectively), because half of the site was prone to waterlogging during the rainy season. From February 1998 to March 1999, four trees of each species in each block were randomly selected as sample trees for measurement. Measurements were recorded in both the dry and rainy seasons during the study period.

One of the eleven species (*Delonix regia*) was excluded from the study because it was not relevant to the context of the study (no nitrogen fixing or used for fodder).

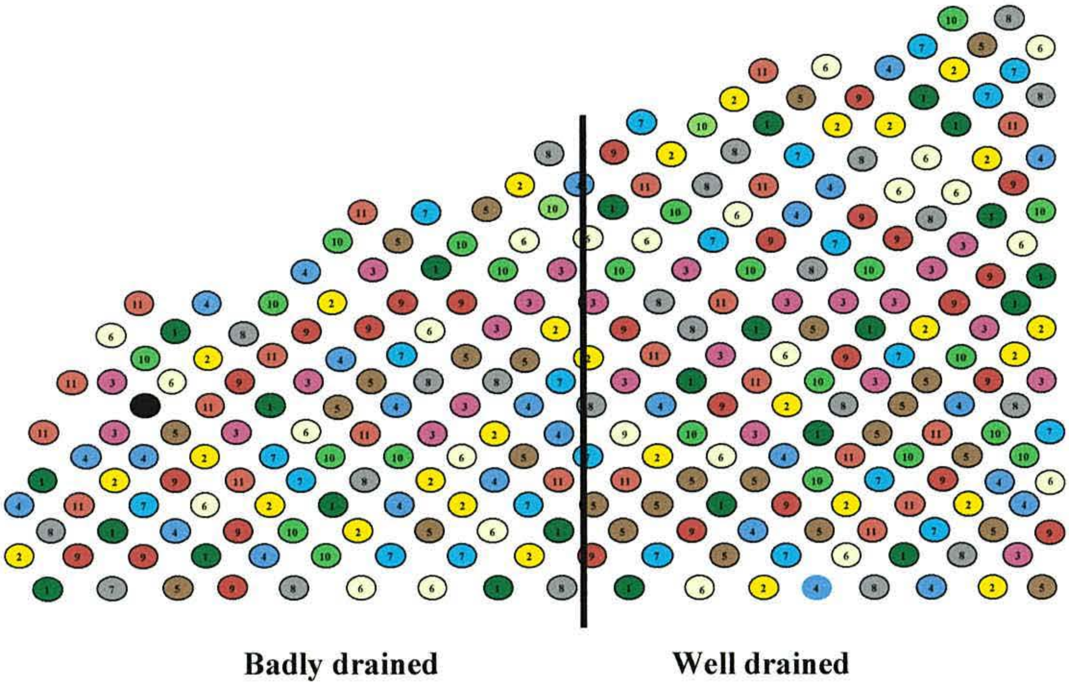


Figure 3.1. Plan of the distribution of tree species in the experimental plot. The species used in this study were: 1: *Gmelina arborea* (gmelina), 2: *Albizia saman* (albizia), 3: *Leucaena leucocephala* (leucaena), 4: *Gliricidia sepium* (gliricidia), 5: *Erythrina fusca* (erythrina), 7: *Enterolobium cyclocarpum* (enterolobium), 8: *Pachira quinata* (pachira), 9: *Cassia grandis* (cassia), 10: *Guazuma ulmifolia* (guazuma) and 11: *Clitoria failcherdiana* (clitoria). Note that 6: *Delonix regia* was not included in the study. Turipaná research centre, Cereté, Córdoba, Colombia.

3.2.3 Pasture productivity and botanical composition

Pasture biomass was measured using a dry weight rank method described in detail by Haydock and Shaw (1975) as modified for tropical pastures by Hoyos et al. (1992). Measurements were made within a 7.5 x 7.5 m area (plot) surrounding each sample tree, with the tree at the centre of the area (Figure 3.2). For each plot, five reference quadrats were selected, which were used as standards against which the biomass of sample quadrats (0.25 m^2) were rated. To construct a five-point scale, two quadrats (standards 1 and 5) were selected in low and high biomass areas. An area estimated to have a dry matter yield half-way between those for 1 and 5, was then selected as standard 3. Then standards 2 and 4 were selected as areas that were estimated to have biomass half-way between those for 1 and 3, and 3 and 5, respectively. Ten further non-destructive quadrats, covering a range of biomass from lowest to highest and with a range of botanical composition, were visually assessed by reference to the standard quadrats. Botanical composition was then visually estimated. Cover of species was assessed and placed into one of five categories; the categories were ranked according to the proportion of the quadrat they covered (45%, 25%, 15%, 10% and 5%). Where cover types exceeded the assigned proportions or if some types were not present, then one cover type could occupy more than one rank position. After all 10 non-destructive quadrats were assessed, the reference quadrats were harvested. The total fresh weight of each quadrat was measured and a 250 g subsample oven-dried at 80°C to constant mass.

Percentage cover (s) per plot of each vegetation component was calculated as:

$$s = \Sigma\, n_i c_i / N \qquad \text{equation 1}$$

Where

i = cover class (1 = 45% cover, 2 = 25%, 3 = 15%, 4 = 10%, 5 = 5%)

n = number of quadrats containing species

c = percentage cover

N = total number of quadrats sampled

Plot biomass B (kg ha^{-1}) was calculated as

$$B = \left(\sum_{i=1}^{10} b_i\right) 4 * 10^3 \qquad \text{equation 2}$$

Where

b_i = quadrat biomass (kg in 0.25 m^2)

Biomass of each vegetation component (Y) was calculated as:

$$Y = Bs \qquad \text{equation 3}$$

Where

B = plot biomass

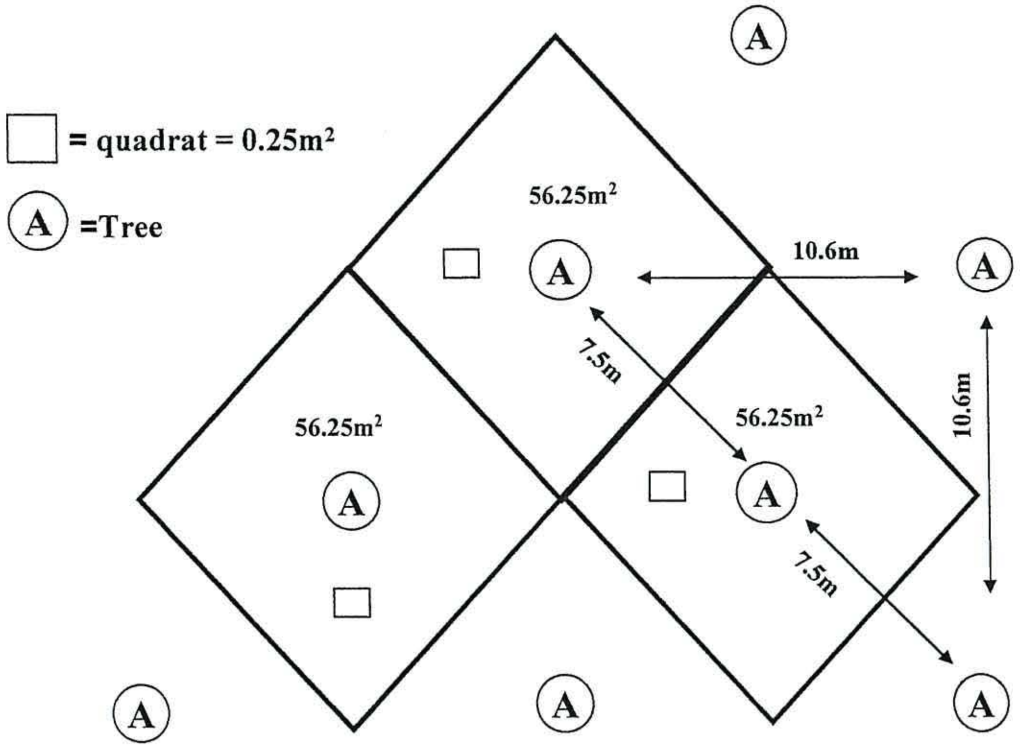


Figure 3.2. Area around each tree used to measure herbaceous biomass. Distances between trees are also shown.

3.2.4 Water use

Measurements of tree water use were focused on three species: *Guazuma ulmifolia,* (guazuma) *Leucaena leucocephala* (leucaena) and *Gliricidia sepium* (gliricidia). Guazuma is an indigenous, evergreen tree with a dense crown. It is highly valued for fuelwood and its fruit, which contain around 20% crude protein, and are an important source of dry season animal feed. The two leguminous species gliricidia and leucaena are renowned throughout the tropics for the quality and quantity of forage they produce. Leucaena is of particular importance during the dry season because it is non deciduous.

Tree water use was measured using a range of constant-power, stem heat balance sap flow gauges suitable for 16-50 mm diameter stems (models SGB16, SGB19, SGB25, SGB35 and SGB50, Dynamax Inc., Houston, TX, USA). Detailed explanation of the technique and associated practical considerations have been described previously (Baker and Van Bavel, 1987; Steinberg et al., 1989; 1990; Smith and Allen, 1996; Grime and Sinclair, 1999). In addition to the manufacturers standard weather shield and aluminium foil, each gauged stem was fitted with a wide conical shelter or 'hat' to reduce direct insolation and prevent water ingress. Gauges were installed on primary branches at least 30 cm above the soil surface. Signals were monitored every 15 seconds via a 32-channel relay multiplexer (AM416) using a programmable datalogger (21X, Campbell Scientific Ltd., Shepshed, UK). Measured signals were recorded as 20 minute means for off-line computation of sap flow rate.

Cable lengths (30 m) and the position of the datalogging systems defined a circular sample area (0.28 ha) containing 20 trees. With two independent logging systems, sample areas within the whole plot were selected to contain a total of four replicate trees of the three species. The same trees were used in both dry and wet seasons of 1998, although sap flow was measured in different branches in each season. Because of a problem with one of the multiplexers, only three of the four replicates were monitored in the wet season period.

Sap flow was measured at different levels of tree leaf area by sequential defoliation, of all replicate trees per species, at weekly intervals. There were no simultaneous control measurements of sap flow in undefoliated trees. Effects of defoliation were more effectively compared through time (before and after defoliation) for replicate trees, because with practical restrictions on the number of replicates, and variability amongst individual trees likely to be more important than variation in conditions through time, this sampling approach reduced confounding effects due to between-tree variability. For comparative purposes, days with similar evaporative demand before and after defoliation were compared. During the dry season measurement period, tree water use was assessed at 100%, *ca.* 75% and *ca.* 50% of initial leaf area, and during the wet season measurements were made at 100% and *ca.* 50% leaf area.

Basal branching structure and stem dimensions were recorded for each sample tree at the beginning of each measurement period. Defoliation was conducted by manually removing leaves. Replicate trees of each species were defoliated on the same day, and defoliation of all three species completed within two days. Consistent levels of defoliation were achieved by removing leaves at repeated intervals along each branch, for example, for the 50% level, every second leaf (leucaena and gliricidia), or every second branchlet (guazuma). For each tree, leaves were separated into two fractions; those removed distal to the sap flow gauge, and those removed from the rest of the tree. Having recorded the total fresh weight of each fraction, a subsample (0.5-1.0 kg) was oven-dried (80°C) to constant weight.

Specific leaf area (cm^2 g^{-1} dry weight) was determined for each fraction, using a subsample of randomly selected leaves (n=10-20 for leucaena and gliricidia, and n≥100 for guazuma). The area of individual leaves was measured using a portable area meter (LL-3000, Li-Cor, USA). Leaves for gliricidia (simply pinnate) and guazuma (simple) were measured within two hours of defoliation. For leucaena, leaf area was measured *in-situ* before 9 am, as the compound bipinnate leaves of this species had a tendency to fold.

The actual leaf area removed at each defoliation was calculated from leaf dry weight and specific leaf area. At the end of each sap flow measurement period, trees were completely defoliated. Initial tree leaf area and leaf area distal to each sap flow gauge was calculated from the sum of the leaf areas removed at each successive defoliation.

3.2.5 Soil moisture

Gravimetric soil water content was measured at the end of each sap flow measurement period in 1998 only for the tree species used to measure sap flow. Using a hand auger the soil profile was sampled in three radial directions, at 120° intervals, around each replicate tree, and at two distances from the trunk for each radial direction (0.5, 1.5 m). For each distance, samples were taken at five depths (0-20, 20-40, 40-60, 60-80 and 80-100 cm). In 1999, gravimetric soil water content was measured for all ten species in both dry and rainy seasons, using four replicate trees of each species in both badly and well drained sites. The same sampling procedure was used as in 1998, except that only one distance from the trunk was used (1.5 m) (Figure 3.3). Soil removed from each depth increment was thoroughly mixed and a subsample of known fresh weight (ca. 200 g) oven-dried to constant weight at 105°C.

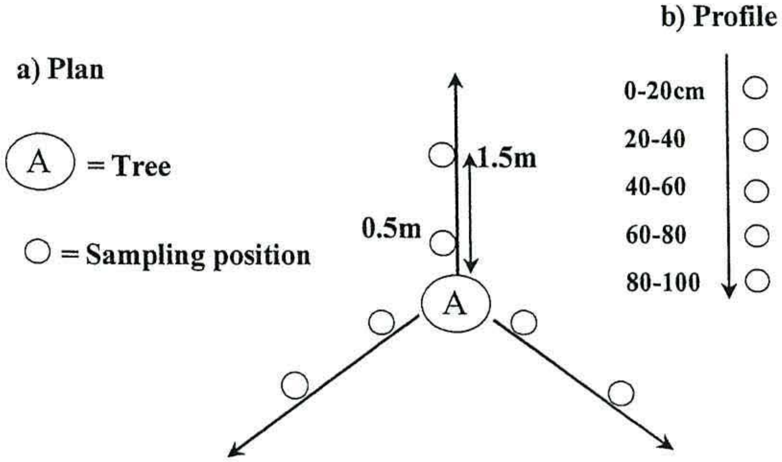


Figure 3.3. Position in horizontal a) and vertical b) space of the samples for soil moisture measurements in single tree plots at Turipaná research centre, Cereté, Córdoba, Colombia.

3.2.6 Tree basal diameter

Gliricidia, leucaena and guazuma were multi-stemmed, therefore all stems found above 10 cm from the ground were measured using callipers. Dimensions of the branches used to measure sap flow were also recorded. Basal diameter was assessed by taking two readings at right angles to each other on each stem at a height of 10 cm from the ground and the mean diameter was used to calculate basal area. Subsequently total basal area for each individual tree was calculated by summing the basal areas of all stems.

3.2.7 Statistical analyses

Dry matter data of herbaceous vegetation was $\log_{10}$-transformed to standarise variances and analysed using a general linear model (GLM), with planned comparisons made between groups of tree species. Sap flow and soil moisture data were analysed using the mixed model procedure, and differences between means were tested using lsmeans in SAS (SAS Institute Inc., 1992).

3.3 RESULTS

3.3.1 Effects of tree species on pasture productivity and composition

Herbaceous vegetation was dominated by grass species, principally *Dichanthium aristatum* (dichanthium) and *Brachiaria mutica* (brachiaria). *Panicum maximun* (panicum) was found but only at a low frequency. *Teramnus uncinatus, Centrosema pubescens* and *Desmodium uncinatum,* were the most common herbaceous legumes. The predominant undesirable species were *Cucumis melo*, *Cassia toro*, *Paspalum fasciculatum*, *Cynodon dactylon*, *Ipomea hirta*, *Paspalum virgatum, Mimosa pudica*, and *Cyperus rotundus*; a complete list of all species is given in Appendix 3.1.

3.3.1.1 Drainage

Overall there was more dry matter produced in poorly drained than well drained conditions (Table 3.1). Dry matter production of all vegetation taxa was significantly affected by drainage except for panicum which was only sparsely distributed across the site, and for legume species. Whereas brachiaria had higher dry matter production in badly drained sites than well drained conditions, all other taxa were more productive on well drained sites (Table 3.1).

Table 3.1. Mean dry matter production (t ha^{-1}) of herbaceous vegetation from February 1998 – March 1999, in relation to drainage, in single tree plots at Turipaná, Colombia. Means are back transformed from logarithms (base 10), n=80 (10 tree species x 4 dates x 4 replicates).

	Site		
Herbaceous Component	Badly drained	Well drained	P-value
Dichanthium aristatum	0.05	0.43	0.0001
Brachiaria mutica	0.66	0.06	0.0001
Panicum maximum	0.0008	0.002	NS
Legume spp.	0.13	0.11	NS
Undesirable spp.	0.01	0.22	0.003
Total dry matter	2.47	2.08	0.003

NS= not significant

3.3.1.2 Season

Total herbaceous biomass showed marked seasonality, with significantly lower biomass in the dry part of the year in both 1998 and 1999 (Figure 3.4).

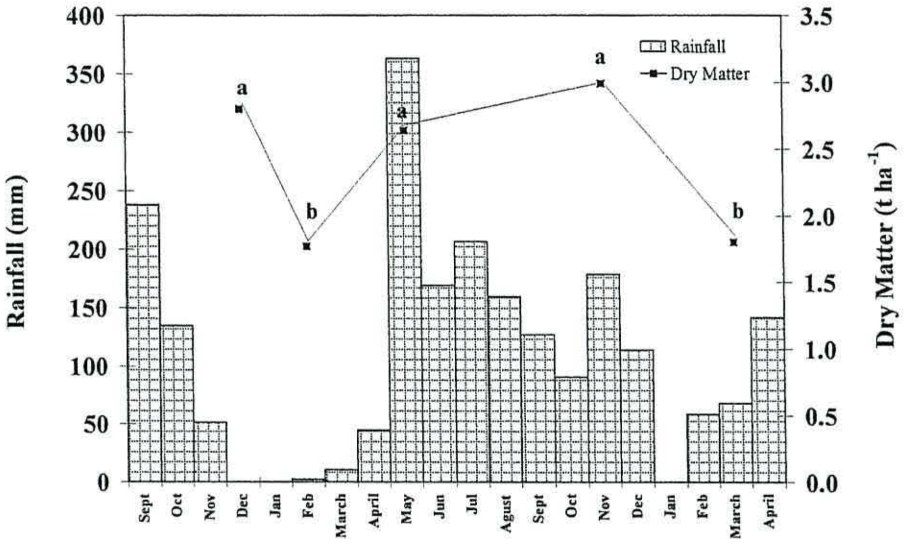


Figure 3.4. Mean total dry matter production of herbaceous vegetation in relation to monthly rainfall from September, 1997 to April 1999, in single tree plots. Means are back transformed from logarithms (base 10). Means followed by different letters are statistically different (P=0.05).

3.3.1.3 Tree species: *Gliricidia sepium* (gliricidia), *Albizia saman* (albizia), *Leucaena leucocephala* (leucaena), *Gmelina arbora* (gmelina), *Erythrina fusca* (erythrina), *Enterolobium cyclocarpum* (enterolobium), *Pachira quinata* (pachira), *Cassia grandis* (cassia), *Guazuma ulmifolia* (guazuma) and *Clitoria failcherdiana* (clitoria).

There was a significant effect of tree species on total dry matter production of the herbaceous vegetation (P=0.02). Mean of dry matter production under trees with sparse crowns (gliricidia, enterolobium, cassia, leucaena and albizia) was significantly higher (P=0.003) than under trees with dense crowns (erythrina, clitoria, gmelina, pachira and guazuma) (Figure 3.5).

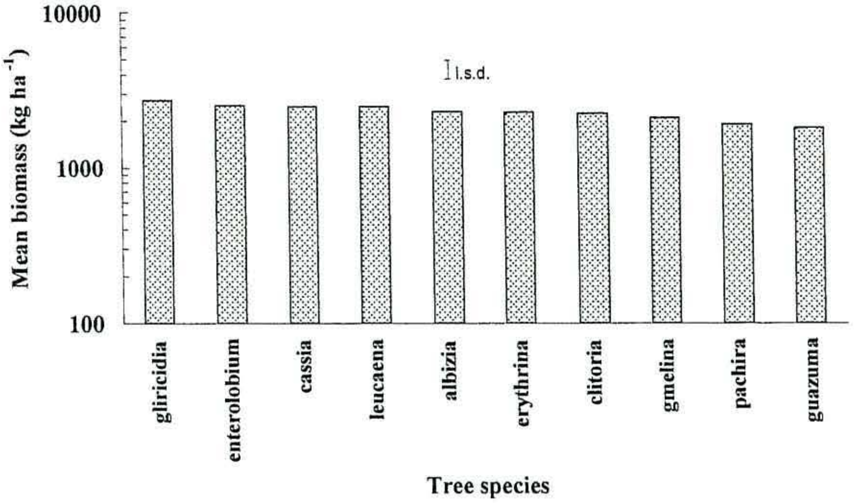


Figure 3.5. Mean of total dry matter of herbaceous vegetation associated with different tree species in single tree plots. Means are transformed back from logarithms (base 10). Bar indicates lsd. (See section 3.3.1.3 for full botanical nomenclature).

In terms of individual pasture components, there were significant effects of tree species on dry matter production of dichanthium, panicum and legume spp. (Table 3.2). Although the contrast between dense and sparse crowned species was significant only for panicum (P=0.013), where higher biomass was associated with dense crowned species (Table 3.2). There was, however, higher biomass production of dichanthium under gmelina and clitoria and the lowest biomass of dichanthium was associated with erythrina (Figure 3.6).

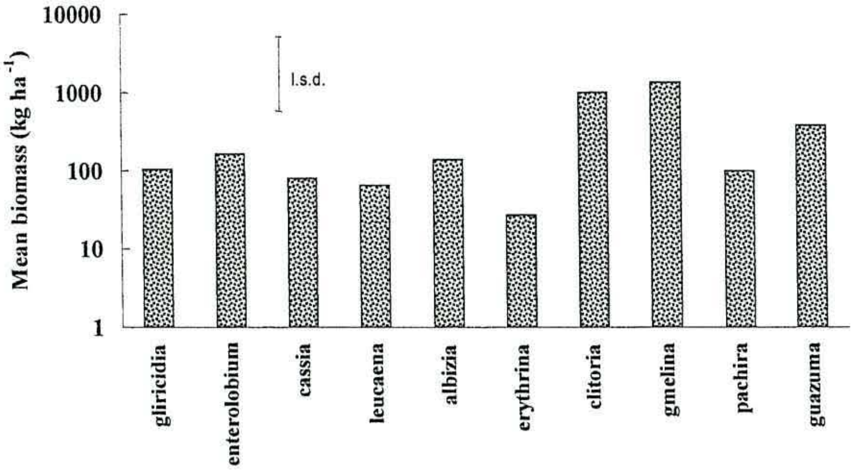


Figure 3.6 Mean of total dry matter of *Dichanthium aristatum* associated with different tree species in single tree plots. Means are transformed back from logarithms (base 10). Bar indicates lsd. (See section 3.3.1.3 for full botanical nomenclature).

3.3.2 Soil moisture

As might be expected, mean gravimetric water content over the whole profile (0-100 cm) was significantly higher (P=0.0001) in the badly drained (28.3%) than the well drained site (22.6%) and significantly lower (P=0.0001) for the dry season (23.5%), than the wet season (26.5%).

Interaction of season and tree species significantly affected gravimetric water content (P=0.0001). All species had higher mean values of soil water content in the wet season than in the dry season. Soil associated with pachira was consistently wetter in both the wet and the dry season than the other species, though not statistically different from leucaena and clitoria in the wet season (Figure 3.7).

Table 3.2. Mean dry matter (t ha^{-1}) of herbaceous components under 10 tree species in single tree plots at Turipaná, Colombia. Means are back-transformed values from logarithms (base 10). *Gliricidia sepium* (gliricidia), *Cassia grandis* (cassia), *Enterolobium cyclocarpum* (enterolobium), *Leucaena leucocephala* (leucaena), *Albizia saman* (albizia), *Erythrina fusca* (erythrina) *Clitoria failcherdiana* (clitoria), *Gmelina arborea* (gmelina), *Pachira quinata* (pachira), *Guazuma ulmifolia* (guazuma).

	Tree species										
Herbaceous component	gliricidia	enterolobium	cassia	leucaena	albizia	erythrina	clitoria	gmelina	pachira	guazuma	P-value
Dichanthium aristatum	0.10	0.16	0.08	0.06	0.14	0.03	1.00	1.33	0.10	0.38	0.03
Brachiaria mutica	0.15	0.40	0.29	0.96	0.15	0.23	0.10	0.12	0.15	0.05	0.55
Panicum maximum	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.024	0.005	0.001
Legume spp.	0.18	0.19	0.16	0.09	0.05	0.04	0.18	0.13	0.14	0.11	0.01
Total biomass	2.8	2.4	2.5	2.3	2.3	2.3	2.1	2.1	2.0	1.8	0.0008

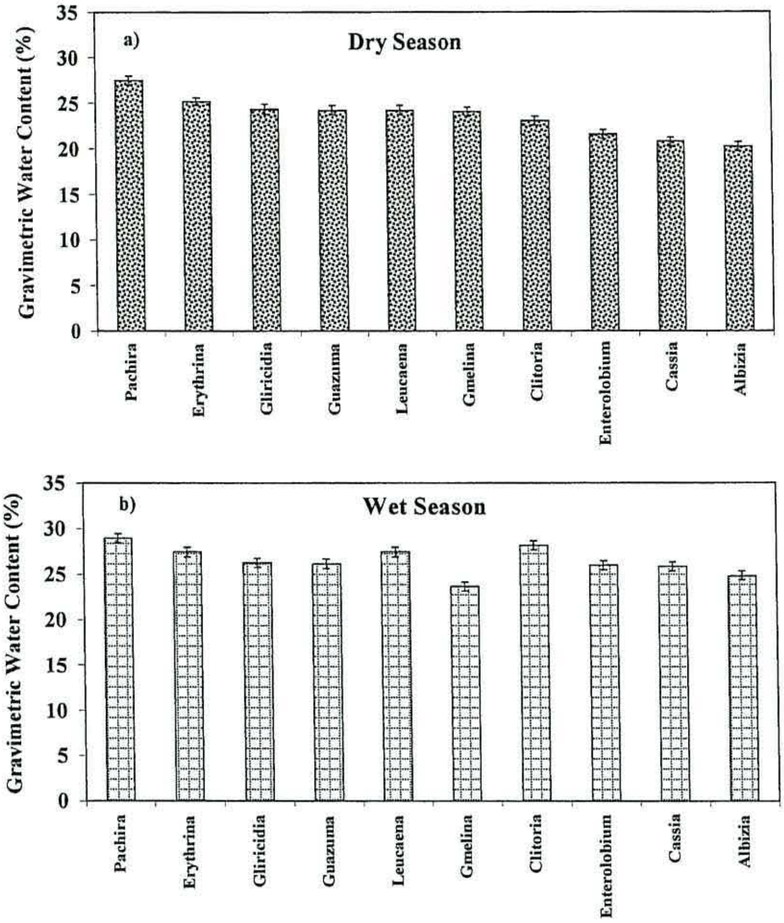


Figure 3.7 Mean gravimetric water content of soil profile (0-100 cm) in relation to tree species and season: a) dry season and b) wet season. Means are from n=120 (2 site types x 4 replicates x 3 radii x 5 depths). Bars indicate standard errors.

Mean gravimetric water content of soil around trees with sparse crowns (gliricidia, enterolobium, cassia, leucaena and albizia) was significantly (P=0.0001) lower (24%) than trees of dense crowns (erythrina, clitoria, gmelina, pachira and guazuma) (26%).

As might be expected, depth had a significant effect on gravimetric water content (P=0.0001), which was lower between 20 and 80 cm than at the surface (above 20cm) and at depth (below 80 cm). The same profile (drier soil at 20-80 cm depth than above and below) occurred in both the wet and dry season, although was more pronounced in the dry season (Figure 3.8). In the dry season water content was higher in the upper part of the profile (0-20 cm) than at 80-100 cm.

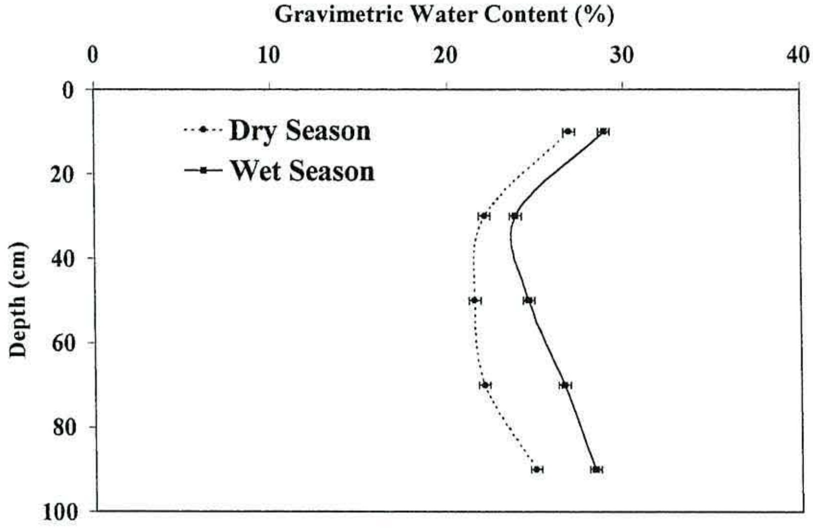


Figure 3.8. Mean gravimetric water content as a function of depth under wet and dry conditions. Data are means of n=240 (2 site types x 10 tree species x 4 replicates x 3 radii). Bars indicate standard errors.

The interactions between season, species and depth were significant for gravimetric water content (P=0.0046). Figure 3.9 shows the means of soil moisture of the tree species plotted as a function of depth in each season. In the dry season pachira and erythrina had the highest gravimetric water content at 0-20 cm (32.0% and 31.3% respectively) and the lowest value was observed in albizia (21.2%). Pachira and clitoria at 80-100 cm registered the highest water content (27.0%) while the lowest was observed in enterolobium and albizia (22.2% and 22.7 respectively) (Figure 3.9a).

In the wet season leucaena had the highest water content at 0-20 cm (33.5%) than the other species while pachira and clitoria had the highest water content at 80-100 cm (31%). The lowest water content at 0-20 cm was observed in gmelina (24.4%) and albizia and enterolobium showed the lowest soil moisture at 80-100 cm (25%) (Figure 3.9b).

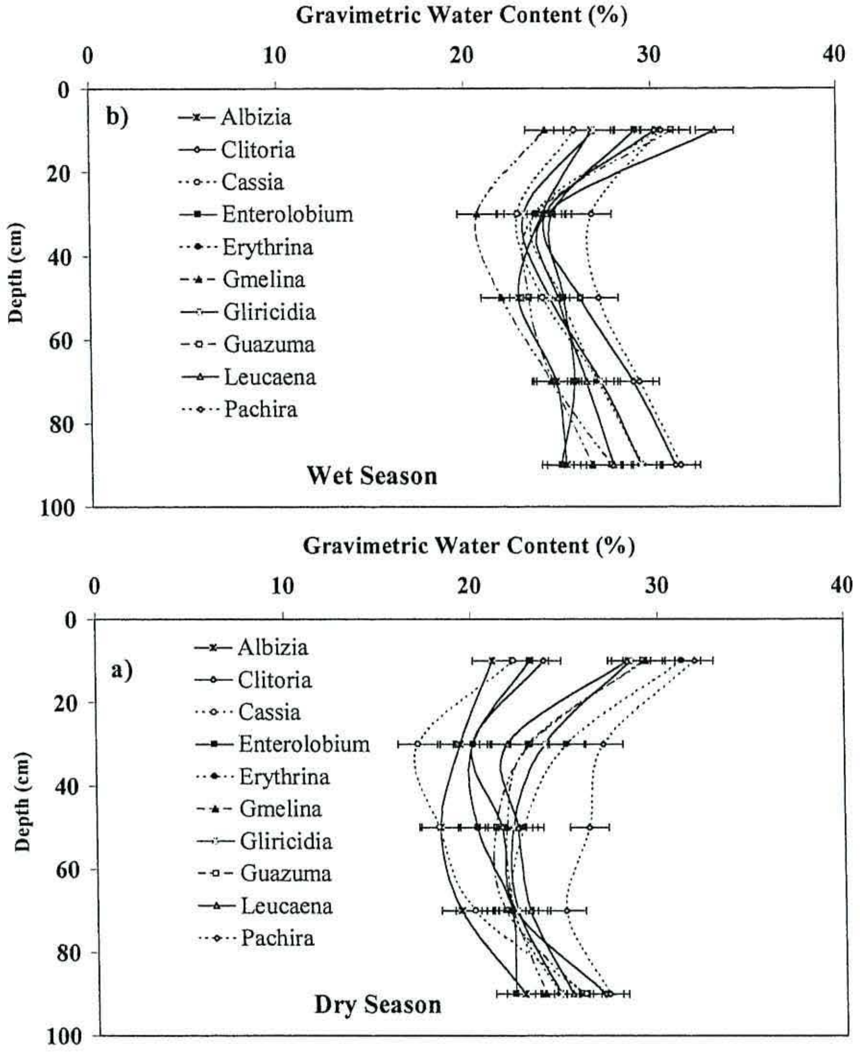


Figure 3.9. Effect of tree species on mean gravimetric water content as a function of depth under a) dry season and b) wet season. Data are means of n=24 (2 site types x 4 replicates x 3 radii). Bars indicate standard errors.

3.3.3 Tree water use

3.3.3.1 Tree size, leaf area and defoliation

Guazuma and leucaena were of similar height (*ca.* 5 m), and significantly taller than gliricidia (P=0.001) at the start of the dry season. However, height growth was negligible for both leguminous species, gliricidia and leucaena, between the two measurement periods, compared with rapid height growth of guazuma, which increased from 4.9 m to 6.8 m (Figure 3.10a). Stem basal area was over four times greater for guazuma than leucaena and gliricidia. For all species, stem basal area increased from the dry to the wet season, and the highest relative increase occurred in gliricidia, which produced many new basal sprouts (Figure 3.10b).

Guazuma supported a significantly higher dry weight of leaves per unit stem basal area (P=0.0001), compared to the other two species, particularly during the dry season (Figure 3.10c). For all species there was a much lower amount of leaf per unit stem basal area in the dry than the wet season, accompanied by lower (P=0.001) specific leaf area (Figure 3.10d). Despite complete defoliation at the end of the dry season measurement period, tree leaf area had surpassed its pre-defoliation level by the June 1988 wet season in all tree species (P=0.0001) (Figure 3.10e).

The extent to which trees were defoliated is indicated in Figure 3.10f, which presents the mean proportion of tree leaf area remaining after each defoliation procedure. For the two measurements recorded in the dry season, the proportion of leaf area remaining was generally slightly higher than the target percentage, particularly in the case of leucaena (82±2% and 59±4% compared to 75% and 50% target figures respectively). For the wet season defoliation, the two leguminous tree species were defoliated by a similar proportion, to leave an average of 60% of the initial tree leaf area, while guazuma was more extensively defoliated, with only 45% of leaf area remaining.

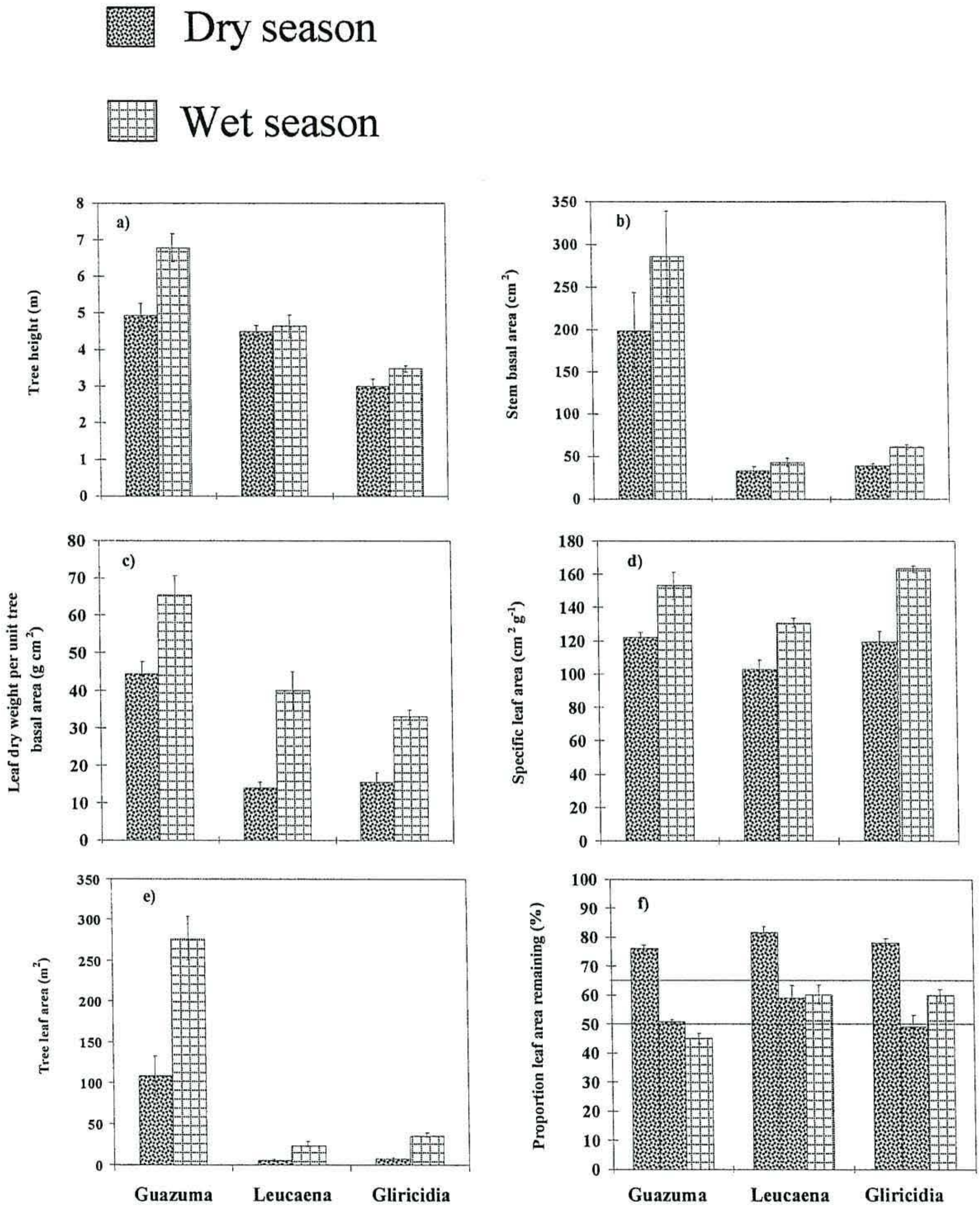


Figure 3.10. a) height, b) stem basal area, c) leaf dry weight per unit basal area, d) specific leaf area, e) tree leaf area for each species and season. Data are mean values of three trees per species. Mean proportion of tree leaf area remaining for each species relative to target levels (75% and 50%) are also shown (f). Bars indicate standard errors.

3.3.3.2 Sap flow

Species differences in sap water use per unit leaf area were highly significant (P=0.0001). In both seasons sap flow per unit stem basal area (F_j/A_j) was higher in leucaena and gliricidia, than guazuma, and comparing the two leguminous species, higher in leucaena than in gliricidia (Figure 3.11a and b).

Species differences in sap flow per unit leaf area (F_j/L_j) were highly significant (P=0.0001). The rate of water loss per unit leaf area in leucaena was significantly higher than in the other species, and higher in the dry season than in the wet season (Figure 3.11c and d). Guazuma maintained a high leaf area per unit stem basal area during the dry season and transpired significantly less water per unit leaf area than the other species (Figure 3.11c and d).

Species differences in tree water use (F_i) were highly significant (P=0.0001) in both seasons. Guazuma used more water than the other two species in the dry as well as in the wet season. Leucaena used more water than gliricidia, but it was significantly so only in the wet season (P=0.03) (Figure 3.11 e and f).

3.3.3.3 Seasonal effects

In general, trees supported a significantly higher leaf area per unit stem basal area in the wet compared with the dry season (Figure 3.12). Although there was a concurrent seasonal increase in the rate of sap flow per unit stem basal area, the response of sap flow per unit stem basal area was less than that of leaf area supported per unit stem basal area, therefore, sap flow per unit leaf area was lower in the wet season than in the dry season (Figure 3.12). The seasonal changes in leaf area supported per unit stem basal area and sap flow per unit leaf area were more pronounced in leucaena and gliricidia than in guazuma (Figure 3.12). Consequently, the seasonal change in tree water use was less pronounced in the two leguminous tree species, and only statistically significant for guazuma.

3.3.3.4 Effects of defoliation

Data presented in Figure 3.12 are the mean values for each species. Although consistently lower at 50% compared to the 100% foliation level, effects of defoliation on sap flow per unit stem basal area (F_j/A_j) were not statistically significant (P=0.22).

There was, however, a higher rate of sap flow per unit leaf area (F_j/L_j) for trees defoliated by 50% (Figure 3.12). So, although tree water use was consistently lower after defoliation, the decrease in sap flow was less than the reduction in tree leaf area, and not statistically significant.

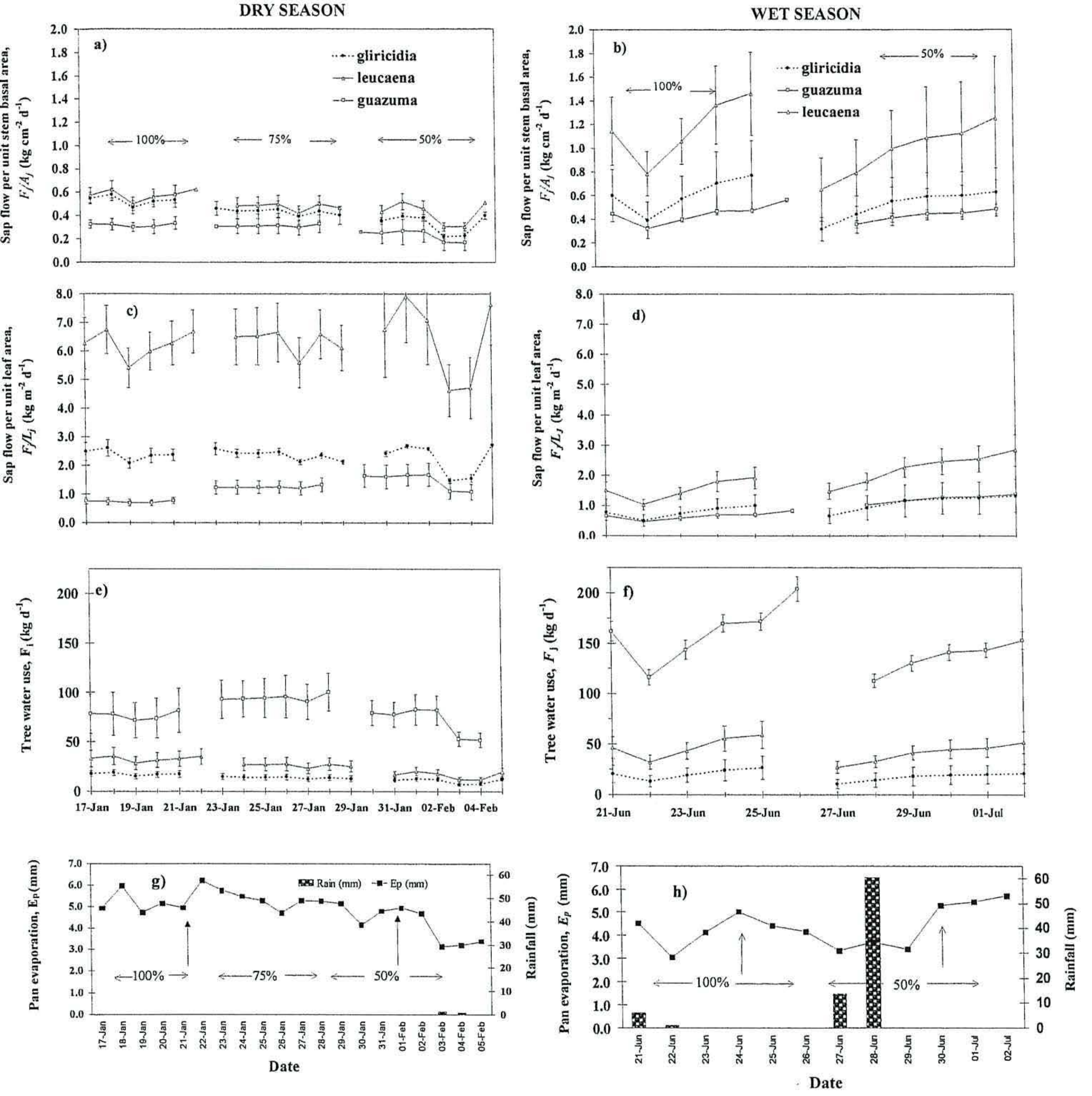


Figure 3.11. Daily sap flow per unit stem basal area in a) the dry and b) and wet season, per unit leaf area for the c) dry and d) wet season and e) tree water use for the dry and f) wet season. Data are the means (± se) of three tree species in the dry and in the wet season. Horizontal arrows indicate the defoliation level in relation to days of measurements. Also shown are daily rainfall and pan evaporation (E_p) for each measurement period (g and h). Vertical arrows indicate days selected as having comparable E_p.

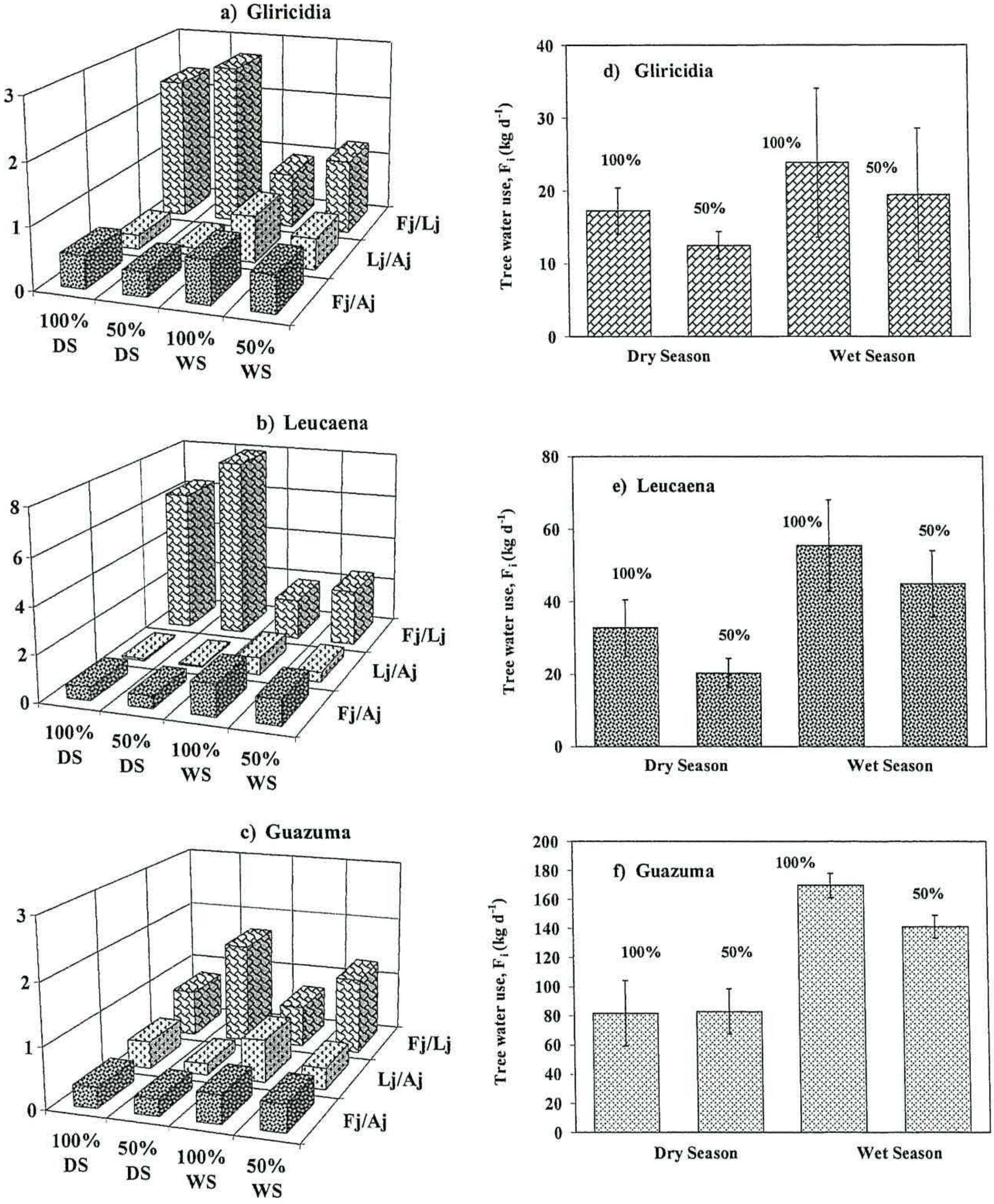


Figure 3.12. Effect of season and defoliation on the ratios of sap flow and leaf area per unit stem basal area (F_j/A_j and L_j/A_j) and sap flow per unit leaf area (F_j/A_j) for each species (a, b and c), and hence on tree water use (d, e and f). Data are means (± se) of three trees in the dry season or in the wet season on days having comparable E_p (21/01/98, 01/02/98 and 30/06/98 for 100% and 50% foliation levels in dry and wet season respectively).

3.3.4 Effects of tree species and season on soil moisture content (sap flow species)

The effects of season, species, depth and the interaction between season and depth on gravimetric water content were highly significant (P=0.0001). Figure 3.13 shows values of mean gravimetric water content over the whole profile (0-100 cm) for each species in both the dry and wet season. In the dry season, mean profile water content (0-100 cm) was significantly higher (P=0.0001) in gliricidia than the other species (Figure 3.13a). In the wet season, mean profile water content was significantly higher for leucaena compared with gliricidia (P=0.0448) and guazuma (P=0.0003) (Figure 3.13b). In both seasons the lowest water content was observed in guazuma. There was no significant correlation between tree water use and soil water content in either season.

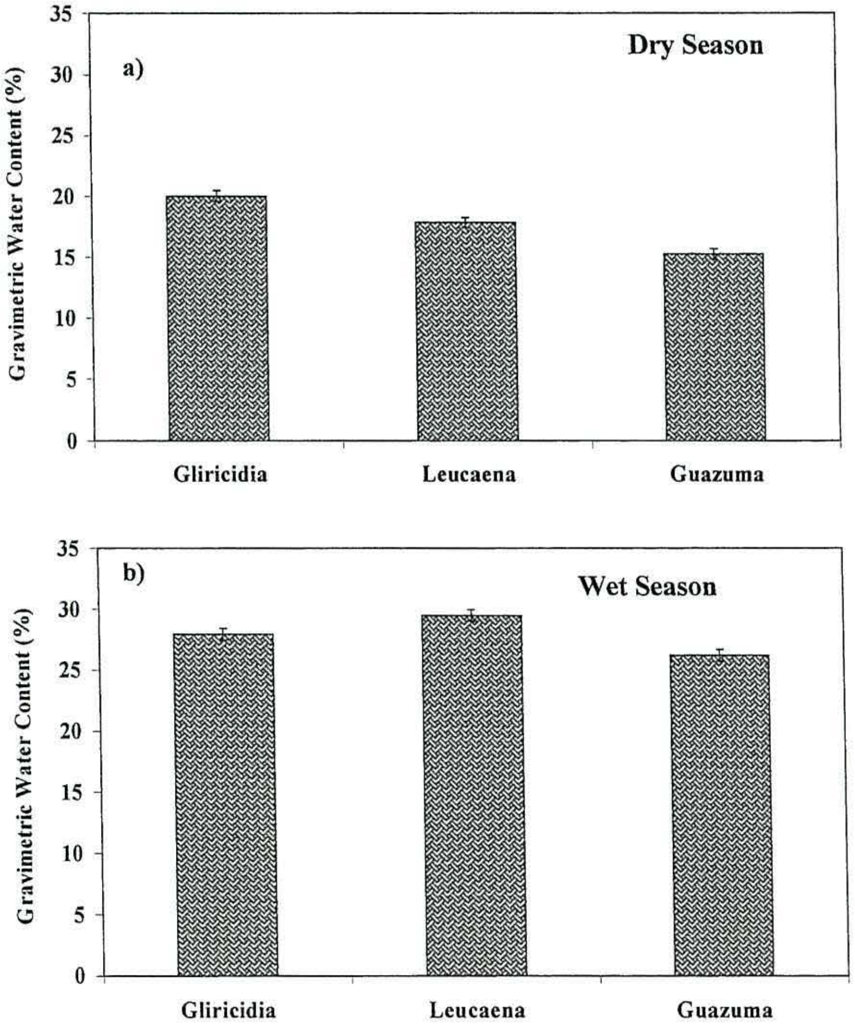


Figure 3.13 Mean gravimetric water content of the soil profile (0-100 cm) in a) dry and b) wet season. Bars indicate standard errors.

Tree proximity had a significant effect on soil water content (P=0.0065), which increased with increasing distance from the tree. Mean profile water content (0-100 cm) was lower at 0.50 m (22%) compared with 1.5 m distance (23%).

Soil water content plotted as a function of depth revealed that, differences in effect of tree species on soil moisture content in the dry season were more pronounced at 60-100 cm than in the upper part of the profile (Figure 3.14a). In the wet season soil water content was higher at 0-20 cm than at other depths. Gliricidia had higher values of water content (33%) than the other tree species in the upper part of the profile (0-20 cm), and at 60-100 cm leucaena showed higher water content (28.1%-31.7%) (Figure 3.14b).

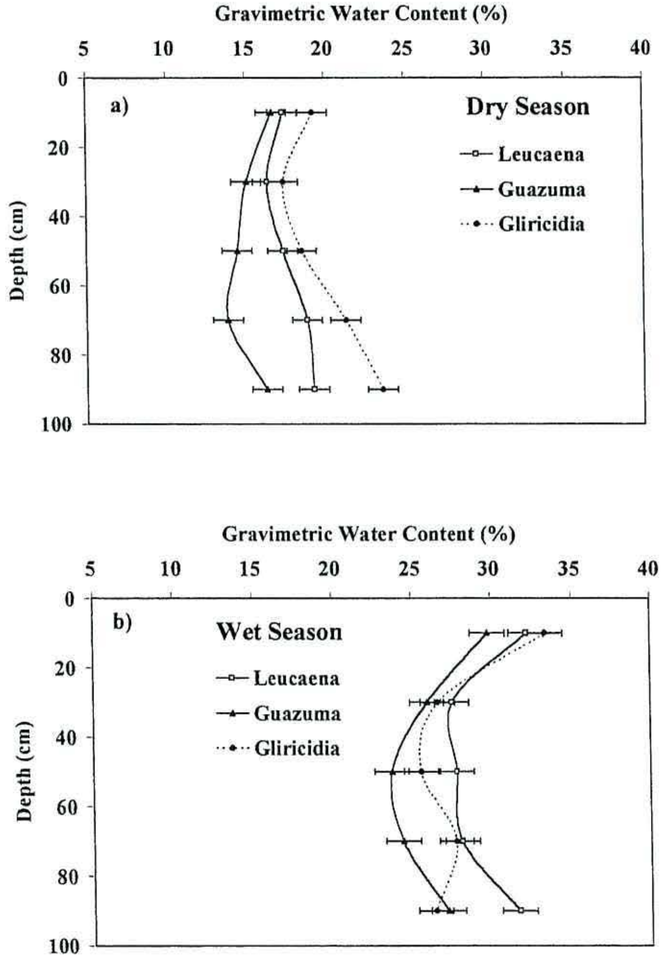


Figure 3.14 Mean gravimetric water content as a function of depth under a) dry and b) wet conditions. Data are mean of n= 72 in the dry season (3 tree species x 4 replicates x 3 radii x 2 proximities) and n= 54 in the wet season (3 tree species x 3 replicates x 3 radii x 2 proximities). Bars indicate standard errors.

3.4 DISCUSSION

The research reported in this chapter comprises two related sets of observations on the effects of trees on pasture productivity and soil moisture for 10 tree species and then a more detailed examination of tree water uptake for three of these species. The results are, therefore, first discussed in two principal sections reflecting each of these contexts, which are then brought together in a final section that draws overall conclusions.

3.4.1 Pasture production

Underlying differences in pasture productivity and composition caused by water shortage and excess in dry and wet seasons respectively may mask effects of the presence of different tree species on pasture production, so these are discussed first, before the complex impacts of tree crowns and root systems on pasture production are considered.

3.4.1.1 Drainage

Drainage was clearly a major factor affecting the biomass of herbage at the site. It is a complex factor, because while poor drainage may result in waterlogging in the wet season, it is also likely to result in higher soil moisture, and hence less water stress, in the dry season as shown for the present experimental site in the contrasting soil moisture profiles for wet and dry seasons (Figure 3.8). The higher overall herbage biomass in badly drained conditions is consistent with greater water retention in the dry season, whereas, the biomass of individual pasture components in relation to drainage, could be explained by differences in tolerance to waterlogging. Brachiaria biomass was higher under badly drained conditions, which is consistent with the observation that it is characterized by its ability to withstand excessive moisture in prolonged floods and waterlogged conditions (Schultzekraft and Toitzel, 1992). In contrast, there was more dichanthium, in well, as opposed to, badly drained conditions, suggesting that it dominated the pasture where tolerance to waterlogging did confer a competitive advantage.

3.4.1.2 Effects of season

As would be expected, the dry matter productivity of herbaceous vegetation varied markedly with season. Dry matter was over 40% higher towards the end of the rainy season in 1998 than in the dry season of that year and the subsequent year (see Figure 3.4). Lower pasture productivity under seasonally dry conditions in tropical pastures has been widely reported in the literature (Belsky et al., 1993; Hernandez and Russell, 2001; Escobedo-Mex et al., 2001). Water shortage is a major constraint to plant productivity in the seasonally dry tropics, even in areas where total rainfall may be higher than 2000 mm per year, but is erratic or unevenly distributed and is exacerbated where there are high losses due to runoff (Boyer et al., 1968; Ong, 1991).

3.4.1.3 Effects of tree species

The presence of trees may have several effects on the microclimate and soil in the environment within which trees are located. Trees have an obvious effect on the microclimate under their crowns by interception of solar radiation (Veetas, 1992), that reduces light and temperature. But, the crowns may also reduce wind speed (Green et al., 1995), leading to higher humidity and lower evapotranspiration from the understorey (Wallace and Batchelor, 1997). This may encourage growth of some pasture species and so promote a changing species composition under tree crowns (Garrison and Pita, 1992). In addition to effects of shade, tree root systems may take up prodigious amounts of water from the soil (Samraj et al., 1988) and so compete with pasture for water. Depending on the extent of horizontal root spread and the fate of leaf litter, trees may either create islands of fertility in savannah ecosystems by concentrating nutrients from a wider area under the crown (Walker et al., 1981. Breman and Kessler, 1995), or take up nutrients as they grow (Sinclair et al., 2000) and lock these up in standing biomass (Chidumayo, 1988). There is evidence suggesting that soils under tree crowns have higher concentrations of organic matter and available nitrogen and other important nutrients, better physical structure and faster water infiltration compared with soils in open grasslands (Belsky et al., 1989, 1993a, Vetaas, 1992).

In the present experiment, overall dry matter of pasture associated with different tree species varied by more than 50%, equivalent to almost 1 t ha^{-1}. This suggests that choice of tree species for use in silvopastoral systems may have a large impact on system productivity and, therefore, is an important management consideration for farmers. In this study, higher pasture biomass was associated with tree species with sparse crown form and lower pasture biomass with tree species with dense crowns, suggesting that shade effects may have predominated over root competition. Sparse crowns, casting a light shade over a wide area, may represent a less competitive means of carrying tree leaf area above pasture than dense crowns, since a given leaf area is more evenly and thinly distributed. Since photosynthetic light response is asymptotic, small reductions in incident light to pasture from high intensities incident to the whole system, over a wide area, would be expected to cause a lower reduction in productivity than larger reductions in light even if they were over a smaller area.

Tree leaf area, however, may intercept rainfall as well as light, reducing the water as well as light input to pasture under the crown (Teklehaimanot and Jarvis, 1991) and since tree transpiration for at a given vapour pressure deficit is a function of leaf area, dense crowns with high leaf area may transpire more water than trees with lower leaf area (see discussion of soil moisture and tree water use below). Effects of trees on soil nutrient availability, are unlikely to have had much impact in the present study because time is required for nutrients to be accumulated, either in standing woody biomass reducing their availability to pasture (Belsky et al., 1993a, 1993b) or in soil under trees through concentration effects of litter fall (Belsky et al., 1993a, 1993b), enhancing availability to understorey pasture. More immediate competition for labile nutrients between tree and grass root systems could have occurred in the present context (Schroth, 1995). Competition for nitrogen may be important; because there were differences between pasture biomass associated with nitrogen fixing and non-nitrogen fixing tree species (planned comparison P= 0.0093).

While it is clear that there were large differences in pasture biomass associated with different tree species, without a no tree control, it is not possible to determine whether these are the result of reduction or enhancement of pasture growth under trees or a mixture of enhancement by some trees and reduction by others. Reduced understorey dry matter of many grasses and legume species was found by Burton et al. (1959) and Ludlow et al. (1974). A number of recent studies, however, have documented that understorey productivity may be improved in dry savannah ecosystems (Walker and Noy-Meir, 1982; Belsky et al., 1993a, 1993b, 1994) and in temperate silvopatoral systems. In seasonally dry savannah ecosystems this can be explained by shade (lower temperature and higher humidity) from tree crowns reducing evapotranspiration from the understorey and thus improving the water relations of below-crown plants (Weltzin and Coughenour, 1990; Amundson et al., 1993). Eastham et al. (1988) using trees planted in Queensland, Australia, at radii of 6.2, 16.5 and 3.9 m from the center of the Nelder design, showed that evapotranspiration losses from pasture were highest at the widest tree spacing and decreased as the pasture was more shaded by the tree crown.

In the present study some herbaceous components seemed unaffected by tree species (brachiaria), while others (dichanthium and panicum) were affected, suggesting that individual species or groups of species have different competitive abilities in different habitats. The higher biomass of panicum under dense crowned tree species is consistent with several studies showing a strong positive association between panicum and tree crown cover. This species often forms pure stands underneath trees and seldom occurs in open areas (Bosh and van Wyk, 1980; Kennard and Walker, 1973; Weltzin and Coughenour, 1990; Wong et al., 1985). Maranga (1986) noted greater shoot biomass of panicum under *Acacia tortilis* than in open grasslands on a semi-arid rangeland in Kenya.

Further research with a smaller number of promising tree species with sparse crown form might usefully include no tree controls to ascertain impacts of introducing trees to sole pasture (impacts of introducing mixed species stands to pasture is explored in Chapter 5). Simultaneous measurements of light interception, microclimatic amelioration and water and nutrient uptake by trees and pasture would be required to explain the contrasting impact of different tree species on pasture growth. Working on the assumption that competition for water in the dry season was likely to be the most important impact of trees on pasture for farmers in the Caribbean region of Colombia, the following sections discuss the measurements of soil moisture and tree water uptake.

3.4.4 Soil moisture

As would be expected, soil moisture varied markedly according to the drainage conditions at the site and with season). Higher soil water content was associated with trees of dense crown form (erythrina, guazuma, gmelina and pachira) than with some species with sparse crown form (enterolobium, cassia and albizia), mirroring the results for pasture biomass. Consistently, soils under drought-deciduous trees with sparse crowns such as enterolobium, cassia and albizia were less moist in both seasons than other species with dense crowns such as erythrina and guazuma. But other sparse crowned species such as leucaena were not statistically different from guazuma or erythrina.

A possible explanation for higher soil moisture under trees with dense crowns would be that lower herbaceous biomass caused by shading from dense crowns, resulted in less herbaceous leaf area and so a lower rate of water use by the understorey. Reduced evapotranspiration may also have occurred under trees with dense crowns as discussed in section 3.4.1.3 above. This has been shown in dry grassland parts of Kenya Masailand where, after rain events, soil moisture was greater, and persisted longer in areas shaded by *Balanites aegyptiaca* trees than in interstitial zones (Glover et al., 1962). Soils under tree shading have been generally reported to be more moist (Joffre and Rambal, 1988; Kennard and Walker, 1973). But effects of trees on soil moisture are complex, for example Belsky et al., (1989) found that soils in an African savanna of Kenya were drier below tree crowns than in surrounding grasslands in the rainy season due to rainfall interception, but in the subsequent dry season, soils were wetter below tree crowns as a result of cooler temperature and reduced evapotranspiration in the shade.

Since soil water content is a balance between inputs at the surface (or from the soil layer above within the profile) and losses through evapotranspiration and drainage, it is not possible to unequivocally determine the reason for wetter soil under some trees than others without measuring all of the components and obtaining a full water balance (Wallace 1996).

Soil water content plotted as a function of depth showed higher soil water content at the surface (0-20 cm) in the dry season than in the deeper layers. This may be a result of small rain events occurring during the dry season. Soils under most of the tree species in the dry season were wetter at the surface, except for albizia, clitoria and cassia, suggesting that these species may more rapidly use water from sporadic rainfall events, possibly through differences in root system characteristics between species. Measurements of root distribution of different tree species would be required to investigate this hypothesis further and recent innovations in fractal techniques (van Noordwijk and Purnomodishi, 1995) may make this feasible.

3.4.5 Tree water use

Having established significant differences in pasture biomass and soil water content associated with different tree species – the extent to which these are explained by differences in water uptake by trees is now discussed for three contrasting tree species. In addition, the extent to which tree water uptake is controlled by the sort of defoliation that might occur through browsing is explored.

The three tree species used significantly different amounts of water per unit leaf area. Species were ranked in the same order in both seasons, leucaena>gliricidia>guazuma, although absolute values were higher under dry compared to wet soil conditions. As species were ranked in the opposite order, in terms of leaf area per tree (guazuma>gliricidia>leucana), while trees of guazuma had more than seven times higher leaf area compared to the two shrub species, tree water use was only three times greater.

The reduction in tree water use as a result of partial defoliation was not directly proportional to the reduction in leaf area because water use per unit leaf area of the remaining leaves increased. Within species, the relative magnitude of this response was similar in both seasons, suggesting that expression of compensatory water use was associated more with microclimatic than hydraulic factors.

Although water use was related to leaf area, this study demonstrated that the constant of proportionality varied not only with season and species, but was also affected by partial defoliation. Since the response to defoliation varied with species, it therefore follows that the potential for manipulating tree water use, and hence management of competition in mixed vegetation systems by appropriate management of tree leaf area, will be species dependent. In this study, partial defoliation was more effective in reducing water use by leucaena and gliricidia than in guazuma.

Leaf removal in this study was uniform throughout the canopy, and did not alter leaf age distribution. Since photosynthetic competence and maximum stomatal conductance varies with leaf age (Jones, 1992), changes in foliar age structure caused by defoliation are likely to influence the degree of compensation. For example, grazing cattle tend to remove young, more palatable distal foliage, so that defoliation through browsing would be expected to alter the balance of leaf age classes, and hence the magnitude of compensation responses. Secondly, here the immediate, short-term response over five days following each defoliation was considered. As the magnitude of a compensatory response usually decreases with time (e.g. Pinkard et al., 1998ab), and the duration may vary between species (Krause and Raffa, 1996), effective management of tree water use via periodic defoliation would require information collected over longer timescales. Thirdly, in addition to the total amount of water used (Sinclair and Grime, in prep.), defoliation may also influence the spatial pattern of soil water extraction (Jones et al., 1998). In some mixed vegetation systems, spatial effects which enhance niche differentiation (Anderson and Sinclair, 1993) may be more important in determining competitive interactions than effects of defoliation on total tree water use.

3.4.6 Effects of tree species and season on soil moisture content

Results of soil moisture measured in relation to the species used for sap flow suggested that the principal distinction between the dry and wet season measurement periods was soil moisture supply, rather than atmospheric demand (Figure 3.12 g and h). In both seasons, soil water content was lowest around trees of guazuma. There was no significant correlation between tree water use and soil water content in either season, although during the dry season, the trend for decreasing soil water content (gliricidia>leucaena>guazuma) did rank in the same order as the increase in tree water use.

Despite the differences in soil water content throughout most of the profile, the magnitude of the differences were small compared to species differences in tree water use. It would seem likely; therefore, that significant extraction of soil moisture occurred below 100 cm.

3.4.7 Conclusion

The initial presumption in this research was that competition for water amongst trees and pasture in the dry season would primarily determine pasture biomass associated with different tree species. It seems more likely from the results that tree shade from dense crowns reduced understorey pasture growth leading to wetter soils because less water was used by understorey vegetation. However, most importantly the experiment has established that there are large differences in pasture biomass associated with different tree species, making choice of tree species an important management decision in establishing silvopastoral systems in seasonally dry pastures. Furthermore, differences in tree responses to defoliation mean that while water use by some species might be controlled by management factors such as intensity of browsing (controlled by animal stocking rate) or pruning, in others, compensatory increases in transpiration per unit of remaining leaf area reduces the extent of control that is possible.

The lack of correlation between tree water use and soil moisture within the top 100 cm of soil suggests that some trees may be getting some of their water from below this depth. Trees that develop tap roots that extract water from below the rooting zone of the pasture are likely to be particularly complementary in their resource use in the dry season. In choosing which species to plant farmers may face a trade-off between higher tree leaf area in more dense crowns, which will also determine tree fodder and fruit production, and competition with understorey pasture. In agroforestry, tree selection has often emphasised the productive aspects of trees leading to use of ideotypes that are competitive with agricultural crops or pasture (Sinclair, 1996). The present results suggest that there are likely to be benefits from including the resource capture characteristics of tree species as selection criteria for silvopastoral systems in seasonally dry pastures because some trees appear to have resource use patterns that are more complementary to pasture than other species. This concurs with Cannel et al. (1996) assertion that a key characteristic of an agroforestry tree is that it should access resources not available to crops.

CHAPTER 4

ESTABLISHMENT AND GROWTH OF TREE AND SHRUB SPECIES IN MULTISTRATA SYSTEMS

4.1 INTRODUCTION

The survey documented in Chapter 2 revealed that farmers in the Caribbean region of Colombia used trees of different stature whose crowns occupy different vertical strata and provide a range of productive and service functions. Furthermore, many farmers had an interest in developing tree resources on their farms, particularly with respect to tree species that they value. Measurements of understorey pasture productivity and water use in single tree plots of several common species (Chapter 3), revealed contrasts in how different tree species affect pasture and respond to defoliation. Critical requirements for developing silvopastoral systems for the region were, therefore, to understand the role of different tree strata and of species within each stratum on system productivity. To investigate this a silvopastoral experiment with different numbers of strata as experimental treatments was established at Turipaná research station. In this chapter the establishment and growth of tree and shrub species is explored in relation to different levels of structural complexity.

The choice of tree and shrub species for use in the multistrata experiment was based largely upon farmers' perceptions as derived in Chapter 2, with some modifications to enhance what could be learned about how mixtures of different woody plants and herbaceous vegetation (grasses and legumes) utilise environmental resources when they share the same site and how they grow as individuals in these contexts.

The conversion of single-stratum, grass-legume pastures to multistrata systems that include several species of taller, long-lived plants involves greater complexity that may confer ecological benefits such as fuller use of resources, lower pest burdens, and compensatory growth (Ewel, 1986) but may also result in competition amongst species

(Keddy, 1989). Plant species with different and complementary patterns of resource use have high "ecological combining abilities" (Harper, 1977) and are likely, therefore, to grow well in mixtures and utilise resources more fully than monocultures of either species alone. There may be large asymmetry in the contribution of different species within mixtures to ecosystem process (Sala et al., 1989) and an increased space utilization both above and below ground resulting from different growth forms may contribute to higher overall productivity of more diverse mixtures than simpler species assemblages (Huenneke and Noble, 1996). There is direct evidence in the humid tropics that complementarity expressed by combinations of species with different stature may increase productivity, resulting in agroforestry systems that have higher primary productivity than monocultures (Haggar et al., 1993). Trees of larger stature provide timber and shade for animals; fodder trees of medium stature (with a substantial proportion of their crown above browsing height) may be particularly valuable if they produce fruits in addition to fodder from leaves; and some species can be managed as browse tolerant shrubs providing high quality green leaf fodder throughout the year and especially during the dry season when pasture productivity and quality is low (Humphreys, 1994; Gutteridge and Shelton, 1993). Particular species may occupy different strata depending upon management, for example both *Guazuma ulmifolia* and *Crescentia cujete* can be maintained as shrubs or allowed to grow into fruit producing arboreals, and *Albizia saman* produces edible fruits as well as being a valuable timber tree.

This chapter describes how an experiment to explore the role of different tree and shrub strata was established and the survival and growth of tree species in different multistrata combinations. Pasture and browse availability, their nutritive value and impact on animal production are detailed in three following chapters (5, 6 and 7).

4.2 METHODOLOGY

4.2.1 Field site, location and general description

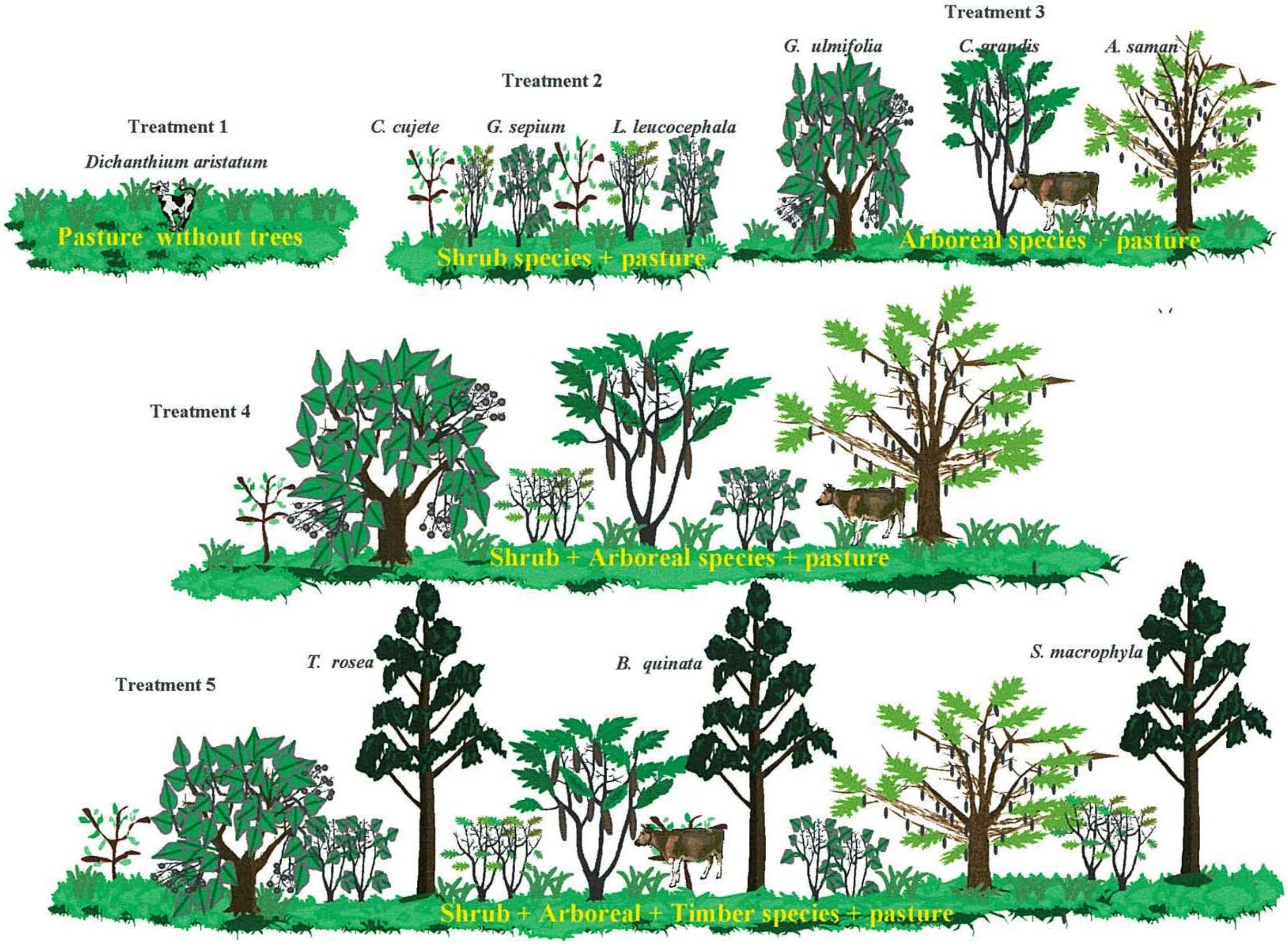
The field site was situated within the Turipaná research centre, Cereté Córdoba, in the Valle del Sinú microregion of Colombia (8°51'N, 75°49'W, 18 m above sea level). The experiment was established on 30 ha of cattle-grazed pasture that was predominantly covered by *Dichanthium aristatum* grass with *Brachiaria mutica* found as a major component in some wetter parts. The most frequent herbaceous legumes found at the site were *Centrosema pubescens, Desmodium uncinatum, Rhyinchosia minima, Teramnus uncinatus,* and *Vigna sp.* A complete list of the flora of the site is given in Appendix 3.1.

4.2.2 Layout and experimental design

A randomized block design with three replications was used. The experiment was established using four multistrata treatments of different structural complexity plus a control with pasture only. The treatments comprised different combinations of four distinct strata: pasture, shrub layer, arboreal (fruit producing) tree layer and timber tree layer. The control treatment contained only pasture, treatments 2 and 3 involved only shrub and arboreal layers respectively in addition to pasture, and treatment 4 combined pasture, shrubs and arboreal strata while treatment 5 had all four strata. The target density of plants was higher for lower strata species (625, 156 and 39 trees ha^{-1} for shrubs, arboreal and timber trees respectively) and a substitutive design was used where multiple strata were combined (Harper, 1977). This meant that treatments 2, 4 and 5 formed a substitutive sequence but treatments 3 and 4 were an additive comparison and treatments 2 and 3 were alternatives. Each of the woody perennial strata contained three species. The shrub layer comprised *Crescentia cujete*, *Gliricidia sepium* and *Leucaena leucocephala* planted in a repeating alternate sequence (see Appendix 4.1 for full details of tree species used and Figure 4.2 for the planting pattern). For the arboreal tree layer, *Albizia saman, Cassia grandis* and *Guazuma ulmifolia* were planted at a lower density but also in a repeating alternate pattern. In treatment 4, in every second row shrubs were replaced in alternate positions by the three arboreal species. This meant that over the plot as a whole, 23% of the total shrubs were replaced by fruiting trees. For treatment 5, in every fourth row arboreal trees were substituted in alternate positions by the three timber species *Pachira quinata*, *Swietenia macrophylla* and *Tabebuia rosea*, which meant that over the plot as a whole, 25% of arboreal trees were replaced by timber trees. Table 4.1 and Figure 4.1 illustrate the differences amongst the five treatments. Figure 4.2 shows the planting pattern of the trees and shrubs.

Table 4.1. Description of treatments in the multistrata silvopastoral systems experiment at Turipaná, Colombia, showing the different levels of tree and shrub diversity.

Treatment	Label	Number of strata	Species
1	Pasture	1	*Dichanthium aristatum* + herbaceous legumes
2	Pasture + Shrub species (producing leaves)	2	*Dichanthium aristatum* + herbaceous legumes Shrub species = *Leucaena leucocephala, Gliricidia sepium, Crescentia cujete* Tree density = 625 trees ha^{-1} 4 m x 4 m planting distance
3	Pasture + Arboreal species (producing fruits or pods)	2	*Dichanthium aristatum* + herbaceous legumes Arboreal species = *Albizia saman, Guazuma ulmifolia, Cassia grandis* Tree density = 156 trees ha^{-1} 8 x 8 m planting distance
4	Pasture + Shrub + Arboreal species	3	*Dichanthium aristatum* + herbaceous legumes Shrub species = *Leucaena leucocephala, Gliricidia sepium, Crescentia cujete* Arboreal species = *Albizia saman, Guazuma ulmifolia, Cassia grandis* Shrub density = 469 trees ha^{-1} 4 m x 4 m planting distance Arboreal tree density = 156 trees ha^{-1} Arboreal trees substitute for shrubs at 8 m x 8 m spacing
5	Pasture + Shrub + Arboreal + Timber species	4	*Dichanthium aristatum* + herbaceous legumes Shrub species = *Leucaena leucocephala, Gliricidia sepium, Crescentia cujete* Arboreal species = *Albizia saman, Guazuma ulmifolia, Cassia grandis* Timber species = *Pachira quinata, Swietenia, macrophylla, Tabebuia rosea* Shrub density = 469 trees ha^{-1} Arboreal tree density = 117 trees ha^{-1} Timber tree density = 39 trees ha^{-1} Timber trees substitute for arboreal trees at 16 m x 16 m spacing

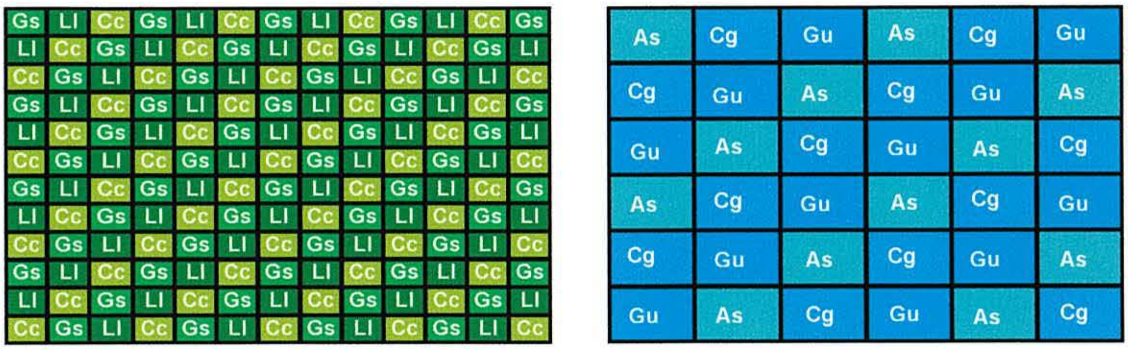


Y.S.Cajas. Research student/SAFS
Corpoica-Colombia

Figure 4.1. Illustration of differing levels of structural complexity and species diversity in treatments in a multistrata silovopastoral experiment at Turipaná research centre. Cereté, Colombia.

4.2.3 Planting conditions

Seeds were sown at the beginning of February and during March 1998, in a nursery at Turipaná research station. *Gliricidia sepium* and *Leucaena leucocephala* were sown in beds, and the remaining species were sown in 15 cm deep black polythene bags. *Guazuma ulmifolia* was first germinated in beds and transferred to polythene bags after germination. *Leucaena leucocephala* and *Guazuma ulmifolia* seeds were sown after inmersion for 1 minute in boiling (100°C) water.

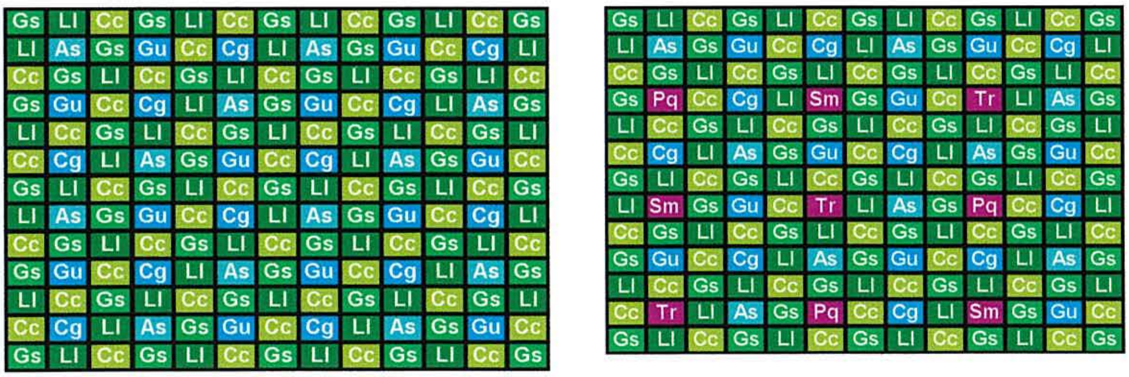


Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs
Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll
Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc
Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs
Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll
Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc
Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs
Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll
Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc
Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs
Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll
Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc

Treatment 2: shrubs

As	Cg	Gu	As	Cg	Gu
Cg	Gu	As	Cg	Gu	As
Gu	As	Cg	Gu	As	Cg
As	Cg	Gu	As	Cg	Gu
Cg	Gu	As	Cg	Gu	As
Gu	As	Cg	Gu	As	Cg

Treatment 3: arboreals



Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs
Ll	As	Gs	Gu	Cc	Cg	Ll	As	Gs	Gu	Cc	Cg	Ll
Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc
Gs	Gu	Cc	Cg	Ll	As	Gs	Gu	Cc	Cg	Ll	As	Gs
Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll
Cc	Cg	Ll	As	Gs	Gu	Cc	Cg	Ll	As	Gs	Gu	Cc
Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs
Ll	As	Gs	Gu	Cc	Cg	Ll	As	Gs	Gu	Cc	Cg	Ll
Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc
Gs	Gu	Cc	Cg	Ll	As	Gs	Gu	Cc	Cg	Ll	As	Gs
Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll
Cc	Cg	Ll	As	Gs	Gu	Cc	Cg	Ll	As	Gs	Gu	Cc
Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs

Treatment 4: shrubs, arboreals

Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs
Ll	As	Gs	Gu	Cc	Cg	Ll	As	Gs	Gu	Cc	Cg	Ll
Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc
Gs	Pq	Cc	Cg	Ll	Sm	Gs	Gu	Cc	Tr	Ll	As	Gs
Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll
Cc	Cg	Ll	As	Gs	Gu	Cc	Cg	Ll	As	Gs	Gu	Cc
Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs
Ll	Sm	Gs	Gu	Cc	Tr	Ll	As	Gs	Pq	Cc	Cg	Ll
Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc
Gs	Gu	Cc	Cg	Ll	As	Gs	Gu	Cc	Cg	Ll	As	Gs
Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll
Cc	Tr	Ll	As	Gs	Pq	Cc	Cg	Ll	Sm	Gs	Gu	Cc
Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs	Ll	Cc	Gs

Treatment 5: shrubs, arboreals, timber trees

Figure 4.2. Plan showing planting pattern of tree and shrub species in treatments 2, 3, 4 and 5 of the multistrata silvopastoral experiment at Turipaná, Colombia. Each treatment plot was 2 ha (only 0.2704 ha are shown here to illustrate pattern of planting). Shrubs were at a density of 625 ha^{-1} (4 x 4 m), arboreal trees at 156 ha^{-1} (8 x 8 m) and timber trees at 39 ha^{-1} (16 x 16 m) with species in each strata occurring in a systematic sequence. Where strata were combined, arboreal trees substitute for shrubs, and timber trees substitute for arboreal trees. The species were: shrubs: *Crescentia cujete* (Cc), *Gliricidia sepium* (Gs) and *Leucaena leucocephala* (Ll). Arboreals: *Albizia saman* (As), *Cassia grandis* (Cg) and *Guazuma ulmifolia* (Gu). Timber trees: *Pachira quinata* (Pq), *Swietenia macrophylla* (Sm) and *Tabebuia rosea* (Tr).

The soil mixture for beds and bags consisted of loam and dry cattle manure, at a ratio of 3:1. All seedlings were kept under dry leaf palm shade and were watered daily in the morning and afternoon. All seedlings were maintained weed-free and those sown in polythene bags were root pruned if they penetrated into the nursery soil.

Once the rainy season was advanced, the seedlings were transferred from the nursery to the experimental plots. Before seedlings were transferred to the field, the herbaceous vegetation of the entire area was cut to ground level using a tractor-drawn grass cutter. All seedlings were hand planted between 24th May and the 15th June 1998. Replacement of dead seedlings was done between 16th June and 16th July in the same year and then again in September after heavy rains. Treatments 2, 3 and 5 of block 3 were seriously flooded at this time and, therefore, extensive replacement planting was necessary in these plots.

Seedlings were planted in plots of 2 ha (98 m x 204 m). Each plot consisted of 25 rows, and each row was demarcated with 50 planting sites at 4 m x 4 m distance, constituting 1250 sites per plot for treatments 2, 4 and 5. Treatment 3 was demarcated with 12 rows and 24 sites per row at 8 m x 8 m distance constituting 288 sites per plot. The shrub species *Gliricidia sepium* and *Leucaena leucocephala* were planted in clumps of four seedlings per site. The remaining species were planted with a single seedling per site.

Manual weeding within a radius of 1 m around the seedlings was done during the first month and then chemical weed control by spraying with a direct application of glyphosate was used to reduce competition during establishment (all seedlings were protected against the glyphosate). During the first 10 months, manual weeding around each seedling was carried out every three months, and subsequently only weeding of climbing weeds was done as necessary (about twice per year). The herbaceous vegetation between rows was kept cut using a grass cutter until grazing started in June 01-1999. Before cattle were introduced to plots, the timber trees were protected with a simple tree guard comprised of blue nylon netting supported by three wooden stakes (2.2 m high x 65 mm diameter) in a triangular arrangement 1 m x 1 m apart, costing approximately 2 USD for materials and 0.3 USD in labour for construction. Cattle were grazed on a rotational basis on the plots from June to September 1999, and from January to May 2000 as described in Chapter 7.

4.2.4 Data recording and analyses

4.2.4.1 Survival of trees

Seedling mortality was recorded in June-July, September and November 1998, January 1999 and April 2000. Data of each species in each block were pooled, arcsin-transformed and analysed using the general linear model procedure in SAS (SAS Institute Inc., 1989).

4.2.4.2 Tree growth parameters

Twenty-five trees per species were randomly selected in each plot to record growth measurements. All trees in all plots were measured four times: in February, July and December, 1999 and in May 2000.

a) Diameter and basal area

Timber trees had single stems and their basal diameter at 10 cm above the soil and diameter at breast height (1.3 m) was measured at each time. Diameter was recorded using callipers, taking two readings at right angles to each other and recording the mean. Shrub and arboreal species were multi-stemmed. All stems above 10 cm from the ground were measured using callipers for each selected tree. Basal diameter of each stem was measured by taking two readings at right angles to each other and recording the mean. Basal area was calculated for each stem of each tree. The total basal area for each individual tree was the result of the addition of the areas of all the stems for each tree.

b) Height

Height at 6 months after planting (February 1999) was recorded for shrub, arboreal and timber species. At 12, 17 and 22 months (July, December 1999 and May 2000 respectively), height was recorded for arboreal and timber species only. Shrub species were excluded from the subsequent measurements because they were lopped at 1.5 m height before grazing started. Subsequently, this height was maintained by grazing animals or lopping if necessary. Height was measured using a graduated pole. For timber species the measurement was from ground level to the tip of the main stem whereas for arboreal species the measurement was from the ground to the highest point of the crown. All data were log-transformed and analysed using the mixed procedure and repeated measures in SAS (SAS Institute Inc., 1993). The lsmeans procedure was used for comparison of means.

4.3 RESULTS

4.3.1 Rainfall

Figure 4.3 shows the mean annual rainfall recorded at the site between 1995 and May 2000. The driest period generally occurs between December and March (<10% mean annual rainfall), while the wettest period is from May to October (>80% mean annual rainfall). In 1997 a lower rainfall than 1995 and 1996 was observed. This lower rainfall was a consequence of the El Niño phenomenon which occurred in 1997, with a severe and extended dry season. In 1998, May and July were the wettest months as well as the months with the highest number of rainy days. June and July were the wettest months in 1999, and July and October had the highest number of rainy days. In the year prior to tree planting (1997-98) December, January, February and March were very dry, while in 1998 and 1999 December was very wet (114 and 110 mm) and January, February and March were consistently dry.

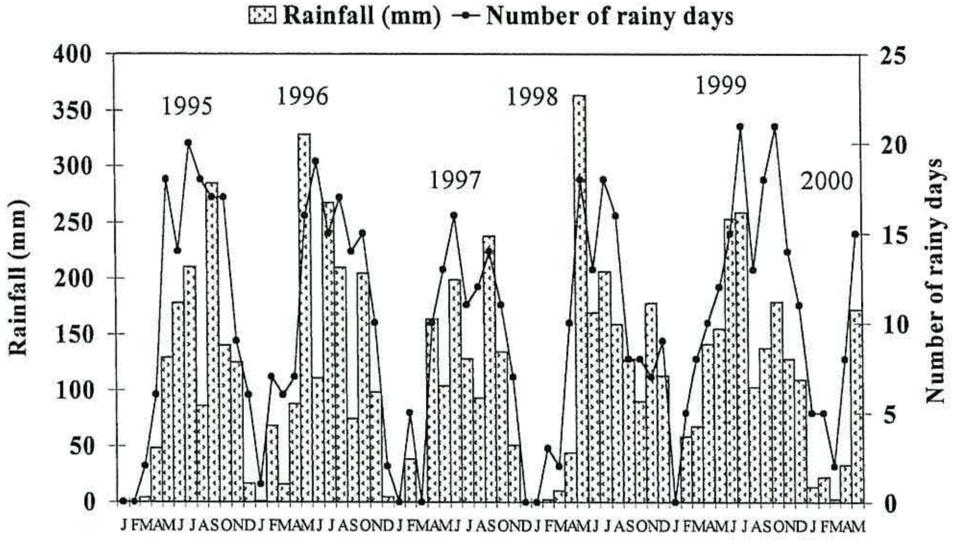


Figure 4.3. Monthly rainfall from 1995 to May 2000 at Turipaná Research Centre, Cereté, Córdoba, Colombia.

4.3.2 Proportion of seedlings replaced

As indicated in Table 4.2, the proportion of seedlings replaced a month after planting was less than 10% except for *Gliricidia sepium* and *Tabebuia rosea*. The proportion of seedlings replaced 2-3 months after planting (in September) was higher in all species than in June-July. *G. sepium*, *T. rosea* and *Swietenia macrophylla* had the highest proportion of seedlings replaced.

Cumulative survival recorded seven months after planting (January 1999) showed that survival ranged between 88.7 and 99.6%, being lowest for *G. sepium* and *T. rosea* (90.0 and 88.7% respectively). However, survival of these species were statistically lower only than *Crescentia cujete*, *Guazuma ulmifolia* and *Pachira quinata*. Results of cumulative survival in April 2000 showed very little further mortality. In the evaluation of April 2000, most species showed survival higher than 90%, except *G. sepium*, *T. rosea* and *S. macrophylla* that were all, nevertheless, above 85%. *G. ulmifolia* had the lowest proportion of seedlings replaced in 1998 and the highest cumulative survival up to April 2000 (Table 4.2).

Table 4.2. Proportion of seedlings replaced in 1998 and subsequent cumulative survival in 1999 and 2000.

	Species	Proportion of seedlings replaced %		Cumulative survival since September 1998 %	
		June-July 1998	September 1998	January 1999	April 2000
	C. cujete	1.1^{a}	5.9^{ac}	98.8^{a}	97.6^{a}
Shrub	*G. sepium*	10.4^{b}	17.4^{bd}	90.0^{b}	86.0^{b}
	L. leucocephala	3.4^{a}	9.0^{c}	95.4^{ab}	92.7^{a}
	A. saman	3.0^{a}	6.4^{ac}	96.6^{ab}	95.5^{a}
Arboreal	*C. grandis*	7.2^{b}	6.7^{ac}	92.6^{bc}	91.1^{a}
	G. ulmifolia	0.3^{a}	2.1^{a}	99.5^{a}	99.2^{a}
	P. quinata	0.0^{a}	12.6^{cd}	99.5^{ac}	98.0^{a}
Timber	*S. macrophylla*	3.5^{a}	21.7^{b}	94.9^{ab}	86.9^{b}
	T. rosea	12.3^{b}	24.5^{b}	88.7^{b}	87.7^{b}

Means within the same column followed by the same letter are not significantly different. Data are back transformed from arcsin.

4.3.3 Stem basal area and diameter

a) Stem basal area of shrub species (*Crescentia cujete*, *Gliricidia sepium* and *Leucaena leucocephala*)

Comparison of treatments 2, 4 and 5 shows that the mean basal area of shrubs were larger where they were mixed with either one (by 34%) or two (by 40%) other tree strata than when grown alone in pasture (P=0.0001).

Figure 4.4 shows the effects of the interaction between treatment and species after shrubs had been growing for the whole evaluation period (1998 to 2000). Basal area for *L. leucocephala* was significantly lower (P=0.0001) than the other two shrub species and it was significantly lower (P=0.0001) in treatment 2 than in treatments 4 and 5. The basal area of *G. sepium* was approximately 50% higher in treatment 4 than in treatment 2 but also higher in treatment 4 than treatment 5. There were marked differences in basal area between individual species in treatment 5 (P=0.0001) with *C. cujete* > *G. sepium* > *L. leucocephala*.

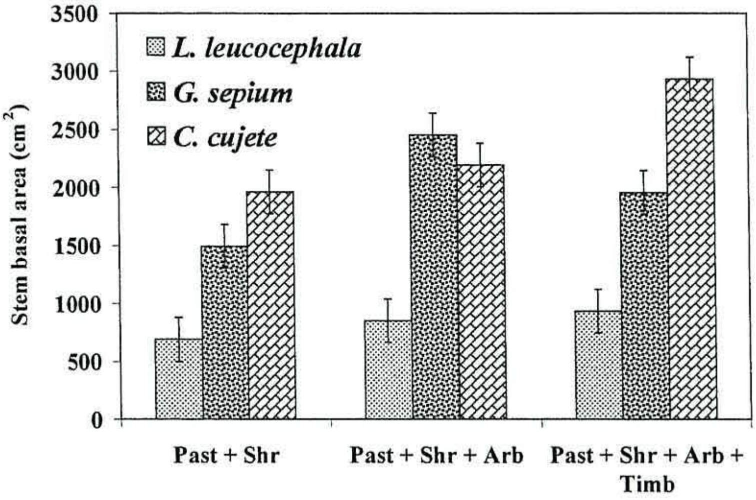


Figure 4.4. Mean basal area of shrub species in different treatments in an experiment with different levels of tree and shrub diversity. Bars indicate standard errors.

b) Stem basal area of arboreal species (*Albizia saman*, *Cassia grandis* and *Guazuma ulmifolia*)

As for the shrubs, arboreal trees grew faster when integrated with other tree strata than when grown alone in pasture. Basal area was 58% and 20% higher in treatment 5 than treatments 3 and 4, respectively, and treatment 4 was 32% higher than treatment 3 (P=0.0001).

The interaction effects between treatment and species were also highly significant (P=0.0001). Basal area was higher in *G. ulmifolia* than other fruiting species in all treatments (P=0.0001), and *G. ulmifolia* grew faster in treatments 4 and 5 than in treatment 3 (P=0.0001). Basal area of *C. grandis* and *A. saman* was also greater in treatment 4 (P=0.017 and P=0.0005 respectively) and 5 (P=0.024 and P=0.0001) than in treatment 3, but there were no significant differences for these species between treatments 4 and 5 (Figure 4.5).

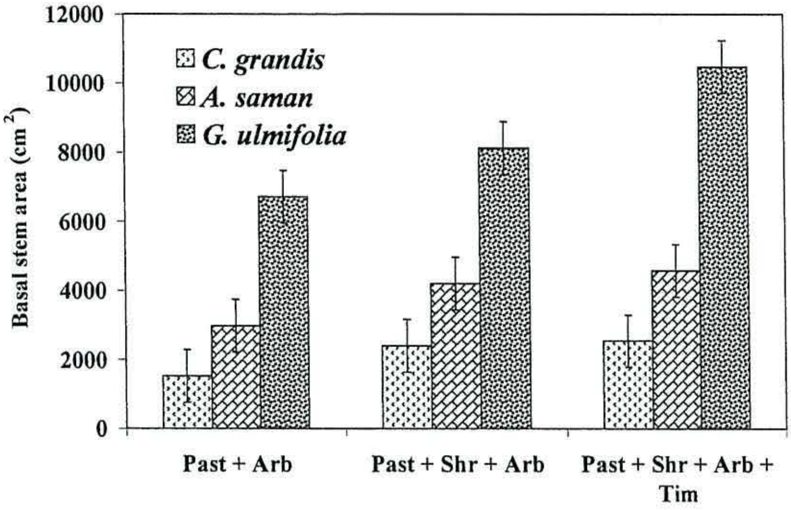


Figure 4.5. Stem basal area of three arboreal species after six months in treatments with different levels of structural complexity. Bars indicate standard errors.

c) Basal stem diameter of timber species (*Pachira quinata*, *Swietenia macrophylla* and *Tabebuia rosea*)

Mean values of species effects on basal diameter are shown in Figure 4.6. There were significant differences between species during all evaluation periods (P=0.0001). At 6 months after planting (February 1999), *P. quinata* had significantly greater basal diameter than *S. macrophylla* and *T. rosea* (P=0.0001). Subsequently, *T. rosea* had significantly greater diameter than the other two timber species, except at 17 months (December 1999), when there was no difference between *T. rosea* and *P. quinata*.

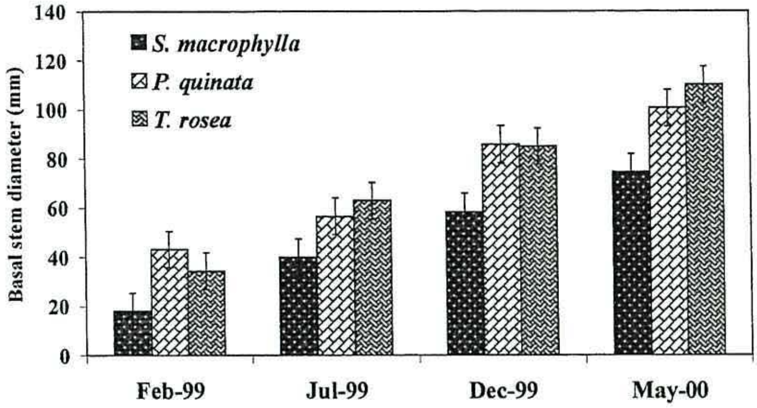


Figure 4.6. Mean stem diameter growth of timber species at different periods after planting in a multistrata experiment of shrub, arboreal and pasture species. Bars indicate standard errors.

d) Diameter at breast height of timber species (*Pachira quinata*, *Swietenia macrophylla* and *Tabebuia rosea*)

Species had a significant effect on diameter at breast height (dbh) (P=0.0001) over all evaluation periods. *S. macrophylla* had the smallest dbh growth, and *T. rosea* was largest (Figure 4.7).

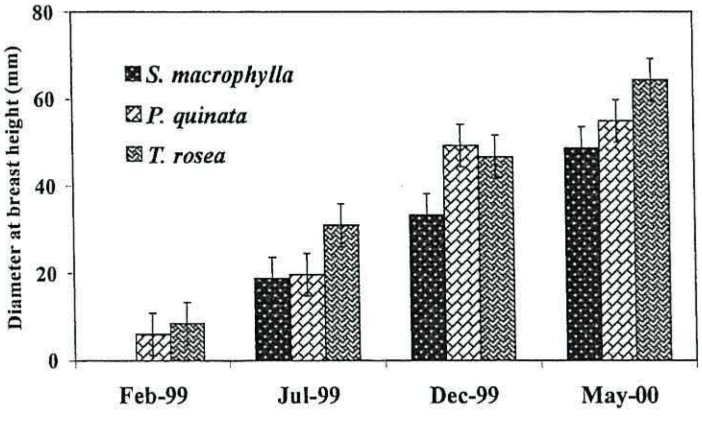


Figure 4.7. Mean diameter at breast height of timber species at different periods after planting in a multistrata experiment with shrub, arboreal and pasture species. Bars indicate standard errors[2]

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[2] Diameter at breast height of *Swietenia macrophylla* in February 1999 was too small to be plotted.

4.3.4 Height growth

a) Height of shrub species (*Crescentia cujete*, *Gliricidia sepium* and *Leucaena leucocephala*)

The effects of treatment on the height of shrub species at 6 months after planting were highly significant (P=0.0001). Overall mean of growth expressed as height at 6 months was significantly higher in the most structurally complex treatments (4 and 5) than in the treatment combining only pasture and shrubs (P=0.0001). Means of height were in the order of 1.2 m in treatment 2 and 1.6 m in treatments 4 and 5.

Species had a highly significant effect on height of shrub species (P=0.0001). *L. leucocephala* was significantly taller than *G. sepium* and *C. cujete* (by 28% and 57% respectively). . *sepium* was significantly taller than *C. cujete* by 28% (P=0.0001).

Figure 4.8 indicates the results of the interaction between treatment and species. The effects of the interaction on height were highly significant (P=0.0001). *L. leucocephala* was the tallest species in all treatments and it was significantly smaller in treatment 2 than in treatments 4 (P=0.0229) and 5 (P=0.0017). *G. sepium* was significantly taller (P=0.0001) in treatments 4 and 5 than in treatment 2.

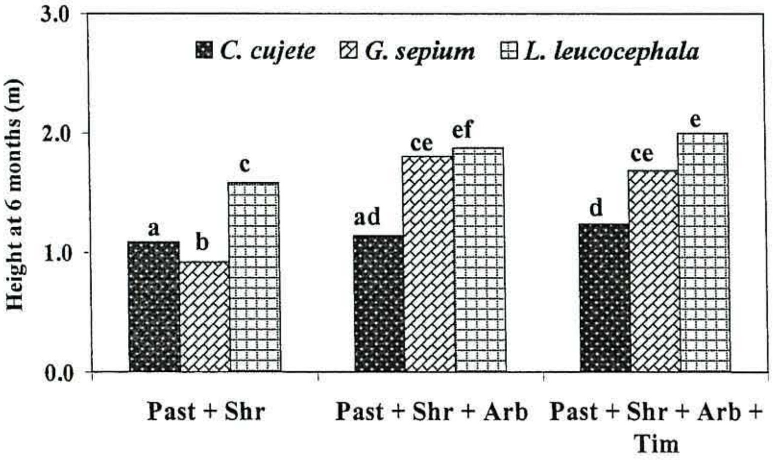


Figure 4.8. Mean height growth of three shrub species in treatments with different levels of tree and shrub diversity at 6 months after planting on grazed plots. Means with different letters are statistically different. Means are back-transformed from logarithmic analysis.

b) Height growth of arboreal species (*Albizia saman*, *Cassia grandis* and *Guazuma ulmifolia*)

Treatment had a significant effect (P=0.0001) on the height of fruiting species assessed at 6, 12, 17 and 22 months after planting. Height was significantly higher in treatment 4 and treatment 5 than in plots of pasture and fruiting trees only (P=0.0001). The overall mean of height per treatment was in the order of 2.1, 2.7 and 2.6 m for treatments 3, 4 and 5 respectively. There was a significant effect of species on height of fruiting trees (P=0.0001). *A. saman* and *G. ulmifolia* were significantly taller than *C. grandis* (P=0.0001). Mean values over the whole period and all treatments were in the order of 2.8, 2.7 and 2.0 m for *A. saman*, *G. ulmifolia* and *C. grandis* respectively.

The interaction between treatment and species assessed at the end of the whole measurement period (1998 to 2000) was highly significant (P=0.0001) on height growth of fruiting species. Figure 4.9 shows the interaction between treatment and species. The results show similar trends to those observed in the interaction between treatment and shrub species.

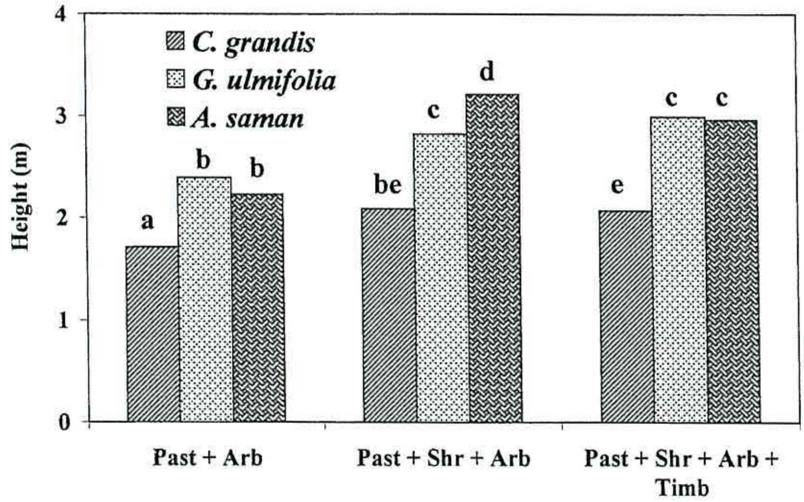


Figure 4.9. Mean height growth of three arboreal species in treatments with different levels of tree and shrub diversity on grazed plots. Means followed by the same letter are not significantly different. Means are back-transformed from logarithmic analysis.

c) Height growth of timber species (*Pachira quinata*, *Swietenia macrophylla* and *Tabebuia rosea*)

Species had a highly significant (P=0.0001) effect on timber tree height. *T. rosea* was the tallest species over all measurement periods. *S. macrophylla* was the smallest at 6 and 17 months after planting. There were no differences between *S. macrophylla* and *P. quinata* at 12 and 22 months after planting (Figure 4.10).

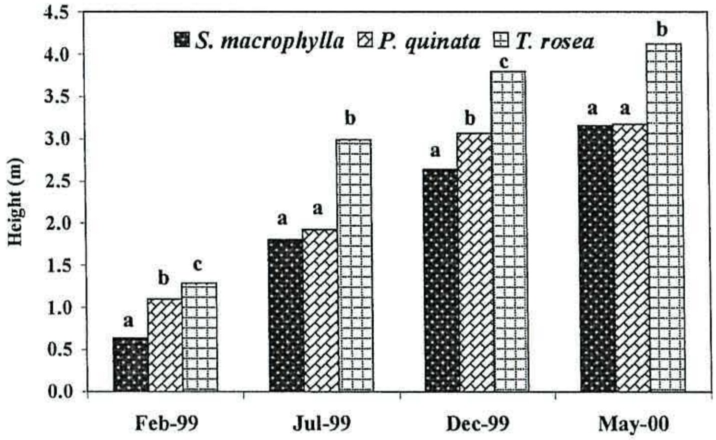


Figure 4.10. Mean height growth of timber species at different periods after planting on a multistrata treatment of shrub, arboreal and pasture species. Means within each period followed by the same letter are not significantly different. Means are back-transformed from logarithmic analysis.

4.4 DISCUSSION

4.4.1 Survival

Between 2% and 12% of the plants of each species were replaced one month after the initial planting, including >5% of *G. sepium*, *C. grandis* and *T. rosea*. Following severe flooding on part of the site, a further 2% to 24% of plants were replaced two months later including >20% of the *S. macrophylla* and *T. rosea* and >10% of the *G. sepium* and *P. quinata*. Four months later, most of these plants had survived, with >90% survival in all species except *T. rosea* (that achieved 89%). There was very little subsequent mortality even after cattle were rotationally grazed on the plots, with all species achieving a cumulative survival greater than 85% 14 months later and all except *T. rosea*, *S. macrophylla* and *G. sepium* above 90%. This demonstrates that high survival rates of trees planted into pastures can be obtained in the region but also highlights the importance of timely replacement of plants in the year of planting if uniform stands are to be achieved. In the 1998 planting season, excess water on poorly drained parts of the site was the major cause of mortality, affecting some species more than others.

Only three species had high mortality *T. rosea*, *G. sepium* and *S. macrophylla*, all of which had slightly below 90% cumulative survival at the final evaluation, following cumulative replacement of more than 25% of the initial seedlings in the first four months. Even these survival figures, however, compare favourably with those reported from other silvopastoral contexts. The survival of *Gliricidia sepium* measured here, for example, was similar to that reported by Ngulube (1994), who measured survival percentages ranging between 82-97% in different provenances of *Gliricidia sepium* one year after planting under alley cropping conditions at Kawinga in Machinga, Malawi. Survival of *Swietenia macrophylla* in this study was considerably higher than that reported by Gerhardt (1993), who found that the highest survival three years after planting *S. macrophylla* was 45% on mown pastures and the lowest 10% in a forest environment. In a secondary forest in the Guanacaste conservation area in Costa Rica three years after planting Gerhardt (1996) reported survival of *S. macrophylla* of only 35%. Browder and Pedlowski (2000) planting in one hectare farms in the Western Brazilian Amazon state of Rondonia found similar survival of *S. macrophylla* (88%) to that reported in this study.

High survival rates of trees are a prerequisite for farm planting to ensure an adequate return to the investment in labour and materials involved in planting, although allowing natural regeneration by reducing stocking rates or eliminating livestock from paddocks is a possible alternative where there is an appropriate seedbank. It should be noted, however, that the survival achieved in the present context was associated with exclusion of livestock from the plots for the first year and mechanical cutting of herbaceous vegetation. While subsequent introduction of cattle did not lead to significant tree mortality, and the simple precautions that had been taken to protect valuable timber species (see section 4.2.3) were effective, the need to exclude cattle from areas while trees are established could be a significant barrier to farmer adoption. Specific on-farm research on establishment methods is, therefore, warranted. A number of options including use of natural regeneration, possibly with enrichment planting, determination of the age at which trees can withstand grazing pressure and protection of young planted seedlings could be explored together with strategies for gradual establishment of silvopastoral systems that only require livestock to be excluded from small proportions of the total grazing area of a farm at any one time.

4.4.2 Growth

4.4.2.1 Timber trees

With mean heights of between 3 m and 4 m and diameter at breast height of 5 cm to 6 cm after 2 years, all timber species were fast growing at the site. *T. rosea* was significantly taller than both other timber species after two years and also had a significantly larger dbh than *S. macrophylla* so that in overall terms the timber tree species ranked in size as follows: *T. rosea* > *P. quinata* > *S. macrophylla*. There was no evidence that growth of the timber trees was adversely affected by grazing. There are few published data on early growth rates of these species. The growth of *S. macropylla* on grazed pasture measured here is, however, significantly greater than *S. macrophylla* planted under different densities of *Pinus caribaea* in the Uxpanapa region of Mexico, which ranged from 1.0 m to 2.2 m two years after planting (Ashton et al., 1998) and that found by Ramos (1992) who planted *S. macrophylla* at different light transmission levels and found that height varied between 0.5 m and 1.9 m during the first eight years of growth. Higher growth rates of trees on fertile pasture at Turipaná than in traditional forest settings might be expected for several reasons. Firstly, soil fertility at the site is high. Secondly, herbaceous vegetation was controlled by initial spot weeding, followed by mechanical cutting and then grazing. Thirdly, with respect to the data for *S. macrophylla* quoted above, the trees in these cases were clearly growing in shaded conditions. Introduction of livestock to control herbaceous vegetation in widely spaced pine plantations is a well established and widespread practice in New Zealand (Knowles, 1991) and the south-eastern United States (Lewis and Pearson, 1987) and cattle have recently been introduced to *P. quinata* plantations in the North of Colombia (Cajas-Girón et al., unpublished data). These results demonstrate that productive associations of cattle and timber trees are clearly possible on seasonally dry pastures in Colombia. It is too early to draw conclusions about the relative merits of the three different timber species. Although there are clearly differences in growth rates amongst species, *T. rosea*, which grew fastest, also suffered much greater mortality than *P. quinata* (see section 4.3.2 above). Further monitoring of the growth of these trees at the site will provide useful comparative information on their timber productivity.

4.4.2.2 Shrubs and arboreal trees

Perhaps the most striking observation in the present experiment is the enhanced growth of shrubs and arboreal trees in multistrata species assemblages (treatments 4 and 5) when compared to simply having either a shrub or an arboreal stratum above pasture (treatments 2 and 3 respectively).

Overall shrub growth, that is, for all species combined, in height and basal area was more than a third higher in the multistrata vegetation assemblages than where a only a shrub stratum was combined with pasture. This is consistent with greater complementarity in resource use between the shrubs and tree species than amongst the shrub species, so that substitution of shrubs for trees results in the remaining shrubs being subject to less competition for resources and hence enhanced growth. Other facilitative interactions may also occur and are discussed below. Treatments 2, 4 and 5 represent a substitutive sequence. However, whereas between treatments 2 and 4 roughly a quarter of the 625 shrubs ha^{-1} are substituted with arboreal species, the difference between 4 and 5 only involves further substitution of a quarter of the 156 arboreals ha^{-1} with timber species (<6 % of shrub planting positions) which would explain why overall shrub growth was significantly higher in treatments 4 and 5 than treatment 2 but not significantly different between the two multistrata treatments. As these data are overall mean growth of three shrub species interacting with up to six tree species, some generality in this finding for this type of environment can be inferred but there were significant differences in growth amongst the shrub species. Higher growth in basal diameter being associated with a greater number of strata was most pronounced for the fastest growing shrub, *C. cujete*, and not evident in the slowest growing species, *L. leucocephala*. The comparative suitability of these shrub species for silvopastoral systems depends upon the amount and nutritional quality of their leaf production, which is, explored in more detail in Chapters 5 and 6.

Similarly to the shrubs, overall arboreal tree growth was enhanced where more strata were present but the comparison amongst treatments is more complex. The addition of shrubs to the arboreal strata (comparison of treatments 4 and 3) resulted in a 32% increase in basal area and a 28% increase in height of the arboreal trees. However, this represents an additive sequence, and since the shrubs have been added and the total density of woody perennials on the plot increased, enhanced growth of arboreal trees is not explained by resource complementarity with shrubs. While a number of facilitative interactions, such as shelter, nitrogen fixation or pest avoidance that are discussed below, might be involved, it is likely that the primary reason for higher growth rates where shrubs are added is that they dilute the impact of cattle on the arboreal trees (this may include effects of browsing and soil compaction as discussed below). The comparison of overall arboreal tree growth between treatments 5 and 4 does represent a substitutive sequence, showing 20% greater stem diameter but no effect on height when timber trees are substituted for a quarter of the arboreals and the shrubs remain unchanged. Comparison of treatments 5 and 3 involves both these additive and substitutive effects simultaneously and shows a concomitantly large enhancement in stem basal area of 58% in the multistrata system together with a 23% increase in arboreal tree height. There are species differences in growth amongst the arboreal trees, with *G. ulmifolia* being much larger in stem basal area than the other two species and *C. grandis* consistently smaller in basal area and height than *A. saman*, though not significantly so in all treatments. While it appears as though *G. ulmifolia* may be a particularly fast growing arboreal tree in these conditions, its value within the silvopastoral system will depend largely upon the production and nutritional quality of its fruit which are explored in succeeding chapters.

4.4.2.2.1 Substitutive effects

As pointed out above, there is evidence here for complementarity in resource use between shrubs and arboreal tree species and between arboreals and timber trees, and of different ecological combining abilities (Harper, 1977) amongst the species in each strata. Higher yields, lower variability of yield from season to season, a better production over the growth period, less susceptibility to disease and an improved quality of the crop product are advantages of mixed systems over monoculture systems (Trenbath, 1974). From de Wit's (1960) seminal studies, it has been suggested that mixed systems often produce more than monoculture, and that some species may have the capacity to exploit resources which are not available to others (Harper, 1977) and subsequently complementary resource use has been suggested as the reason for increased productivity of combinations of different plant life forms in tropical forests and agroforestry systems (Haggar and Ewel, 1997; Cannell *et al.*, 1996).

Haggar and Ewel (1995) reported faster growth of individual trees of *Hyronima alchorneoides* and *Cordia alliodora* in mixed stands than in pure stands. Their study suggests that the higher growth in mixed systems may have been due to differences in crown and root-system geometry that enabled the species to partition space, and hence resource use (Cannell *et al.*, 1996) effectively. In the present context, crown properties are unlikely to have had a major impact on competition for resources because the plants were at least 4 m apart and only up to 2 years old with occurrence of periodic browsing, so that canopy closure across plots was not approached. It, therefore, seems more likely that complementarity in capture of nutrients and/or water below-ground resulting from different rooting patterns in space and/or time may be involved. *C. cujete*, *G. sepium* and *L. leucocephala* are fast growing species, the two latter legumes are likely to fix nitrogen (Giller and Wilson, 1991; Brewbaker, 1986) but primarily root in surface soil horizons (Ong et al., 1996) especially if periodic browsing stimulates superficial root development (van Noordwijk *et al.*, 1996). The arboreal and timber trees that were not restricted in their height growth and so increasingly developed crown volume above browsing height might also be expected to have developed deeper root profiles and hence spatial niche differentiation (Harper, 1977) with respect to shrubs. There could also be temporal differences in resource capture amongst the species stemming from different leaf phenology (Sinclair *et al.*, 2000) and hence root growth and water and nutrient uptake, that would be accentuated by browsing of the shrubs. Caution is required in making generalisations about root distributions of particular species, however, since root distributions in the field are a product of genotype x environment interaction (van Noordwijk *et al.*, 1996) and trees exhibit plasticity in response to nutrient and water depletion by competitive swards (Campbell *et al.*, 1994; Tomlinson, 1992). Similarly, leguminous species may have a capacity to form rhizobial associations and fix nitrogen and hence compete less for nitrate and ammonia in soil, but depending upon soil conditions they may also obtain some or all their nitrogen requirement through root uptake (Giller and Wilson, 1991). The present observation of enhanced growth in multistrata systems, particularly of some species, is useful in itself, but further ecophysiological research would be required to confirm the extent and mechanism of resource complementarity involved, which might help in extrapolating results to a wider range of site conditions and species.

4.4.2.2.2 Additive effects

The addition of shrubs to an arboreal tree stratum thereby increasing the density of woody perennials from 156 to 625 plants ha^{-1} will clearly reduce the intensity of interaction between cattle and the arboreal trees. There could also be effects of cattle on soil compaction where animals spend more time close to trees. Animal compaction of soil around trees has been shown in silvopastoral systems involving cattle in Canada (Bezkorowajnyj *et al.*, 1993) and sheep in the UK (Sibbald *et al.*, in press) with lower tree densities resulting in greater livestock pressure and reduction in early tree growth (Sibbald et al., in press).

4.4.2.2.3 Facilitation

In both the substitutive and additive situations described above, enhanced growth may also result from facilitation, where one species or strata provides direct benefits to others rather than reducing competition for resources (Anderson and Sinclair, 1993). There are many possible mechanisms that could operate in the present context, such as provision of nutrients through nitrogen fixation or nutrient cycling from depth (Young, 1997), accumulation of organic matter through litterfall (Young, 1997), reduction in windspeed (Green et al., 1995) and manipulation of the prevalence of pest and disease organisms and/or their predators (Vandermeer and Perfecto, 1998). There are no specific indications regarding which, if any, of these mechanisms were important at the site, over the measurement period in question and further research, as in the case of resource complementarity discussed above, would be required to elucidate the controlling factors.

4.4.3 Conclusions

Tree establishment at the site was generally good with high survival and fast growth, except for high mortality of some species in a few plots adversely affected by severe flooding in July and September, 1998. This demonstrates that productive associations of trees on grazed pasture can be established in this environment if animals are excluded in the first year. Further on-farm research on establishment methods focussing on natural regeneration, enrichment planting and systems for protecting planted seedlings would be merited with an aim of reducing or avoiding livestock exclusion thereby making it easier for farmers to invest in establishment. More significantly, there was evidence of higher growth rates of shrubs and arboreal trees when they were mixed with other strata than when grown alone with pasture. This is consistent with effects of resource complementarity where arboreal or timber trees were substituted for plants in other strata and with reducing livestock impact on arboreal trees where shrubs were additional to an arboreal tree stratum. As it is revealed in the next chapter that pasture productivity was unaffected by addition of trees at the site, the enhanced tree growth reported here represents significantly higher primary productivity in multistrata systems over less structurally complex vegetation.

CHAPTER 5

FODDER PRODUCTIVITY OF BIODIVERSE MULTISTRATA SILVOPASTORAL SYSTEMS

5.1 INTRODUCTION

The planting of trees in improved pastures has been increasingly recognized as a useful land use practice for income diversification (Mead, 1995), a conservation measure against soil erosion (Young, 1997) and as an enormous potential source for feeding animals in areas when a major constraint to higher productivity from ruminants is the low availability of good quality feeds, especially during the dry season and periods of drought (Devendra, 1992; Gutteridge and Shelton, 1994; Aletor and Omodara, 1994; Rosales and Gill, 1997).

Sustainable forage production from mixtures of browse species and pasture in the tropics depends largely on the ability of the components within the system to capture biophysical resources (light, water and nutrients) at a given location (Ong, 1991). Pasture growth in mixed systems with trees is affected by the way in which the trees alter the availability of resources available to the pasture (Bosh and Wyk, 1980; Robinson, 1985; Belsky, 1994a). Herbaceous plants under tree crowns may receive less light, experience less severe evaporative demand and have access to either a lesser or greater soil water and nutrient supply depending on various attributes of the tree involved (Weltzin and Coughenour, 1990; Wilson, 1998). The relative effects of these factors can result in either reduced (Ericksen and Witney, 1981; Somarriba, 1988) or increased (Durr, 2001, Durr and Rangel, in press; Wilson et al., 1986; Wong and Wilson, 1980) productivity in understorey vegetation compared with surrounding open areas. The effects, however vary seasonally and are apparently related to local climatic regimes (McClarand and Bartolome, 1989).

Cattle production is the main land use in the Caribbean region of Colombia. These grasslands on which the cattle are raised have a tree layer (see Chapter 2) and a herbaceous layer usually dominated by *Dichanthium aristatum* and *Bothriochloa pertusa*. The major limitation to animal production of these grasslands is the low quantity, and in some cases, quality of the pasture. The environment is characterized by variable rainfall both between and within years (see Chapter 4, Section 4.3.1). Between-year variability leads to large annual variations in forage production, while within-year variability produces short-term variation in both pasture growth rates and quality. Trees were present at densities ranging from <3 to >50 ha^{-1} on from a quarter to two-thirds of farmland surveyed in the Caribbean region of Colombia (Section 2.3.1 and Table 2.4) and of the 94 tree and shrub species identified, 14 were frequently classified by farmers as being used as fodder (Section 2.3.2 and Figure 2.5). Despite this prevalence of trees on pasture, their role and their interactions in the farming systems of the region has not been studied and remains largely unknown. Therefore, there is a clear need to evaluate and determine the forage potential of the predominant tree and shrub species and their interactions with pasture grasses, herbaceous legumes and grazing animals, which may lead to the development of more productive and sustainable livestock systems in the region.

In Chapter 4 the establishment and early growth of tree and shrub species in a multistrata experiment were presented. In this chapter the species composition and dry matter production of the herbaceous layer during the establishment of the trees in the same experiment are investigated together with the fodder dry matter production from the trees, which includes leaf biomass of the three shrubs and also fruit from the one arboreal tree species, *Guazuma ulmifolia*, that had commenced fruiting during the establishment phase. The nutritional value of the tree fodder is then investigated in Chapter 6 and the animal production that the various treatments supported is explored in Chapter 7.

The overall objective of the research reported in this chapter was to evaluate forage biomass of herbaceous vegetation and shrub species when combined in a multistrata silvopastoral system. This involved exploring four key hypotheses that are set out below.

1. The presence of trees reduces understorey pasture biomass through dominance of competitive over facilitative interactions.
2. The presence of trees modifies botanical composition of the understorey because tree competition changes resource availability, which favours different species than in open conditions.
3. Total forage biomass from grass and trees is higher in tree-pasture combinations than in pasture alone, as a result of higher overall resource capture in mixed systems so that additional tree forage biomass more than compensates for any reduction in herbaceous leaf biomass.
4. Tree forage biomass is a more important component of total forage biomass in mixed systems during the dry season than in the wet season because trees have different phenology to herbaceous species and the extent of this effect varies:
        amongst tree species, and
        in relation to the configuration of trees in the system,
   because of differences in phenology amongst tree species and differences in their response to competition from other trees.

5.2 METHODOLOGY

5.2.1 Herbaceous-layer productivity and botanical composition

At the beginning of the rainy season in May 1998, herbaceous biomass was recorded in each of the fifteen experimental plots described in Chapter 4, comprising three replicates of five treatments involving different combinations of four strata: pasture, shrubs, arboreal (fruit producing) trees and timber trees. Subsequently, biomass was recorded in September and November 1998, and March 1999. These three measurement periods corresponded to the establishment period of the trees before cattle were introduced to the plots. During the grazing period, herbaceous biomass was recorded before each plot was grazed and after the cows vacated the paddocks, from June 1999 to April 2000 when the plots were rotationally grazed with 10 days grazing followed by 40 days rest (see Chapter 7 for further details). The measurement periods will be referred to as wet season 1998 (September and November), dry season 1999 (March), wet season 1999 (June to December), dry season 2000 (January to April) and wet season 2000 (May and June 2000).

Herbaceous biomass was assessed using the dry weight rank method previously described in detail in Chapter 3 Section 3.2.3. Cover of vegetative components (grasses, herbaceous legumes and undesirable species) was visually estimated in forty 0.25 m^2 quadrats within each plot, by assigning components within quadrats to one of three cover categories (70, 20 or 10%). Components were able to occupy more than one category where appropriate. Calculation of percentage cover of each component of the vegetation and plot biomass were as described in Chapter 3 Section 3.2.3, with modification of Equation 2 to take into account the larger number of quadrats sampled.

5.2.2 Forage biomass of shrub species

Forage biomass of the shrub stratum species: *Crescentia cujete*, *Gliricidia sepium* and *Leucaena leucocephala* was measured in February-March, July-August and October-November 1999 and in February-March 2000 using the twenty-five trees previously selected at random per plot to assess height, diameter and stem basal area (Chapter 4 Section 4.2.4.2). Forage biomass measurements were conducted by manually removing all leaves of each sampled tree. Having recorded the total fresh weight of forage biomass of each tree, a subsample (1.0 kg) was oven-dried at 80°C to constant weight, to calculate dry matter.

5.2.3 Number of primary and secondary branches

At each shrub leaf biomass evaluation, the number of primary and secondary branches (Huxley, 1985), as well as the number of basal sprouts, was recorded for each of the twenty-five sample trees in each plot.

5.2.4 Fruit production

Fruit production was recorded during the dry season of 2000 for *Guazuma ulmifolia*, the only species producing fruits during the evaluation period.

5.2.5 Statistical analyses

Distribution of measurements of herbaceous layer productivity and botanical composition were not normally distributed, so dry matter values were transformed to natural logarithms before analysis, while botanical composition values were transformed to arcsin since they were percentages (SAS Institute Inc., 1993).

Dry matter and botanical composition of herbaceous vegetation, shrub leaf biomass, number of primary and secondary branches and number of basal sprouts and fruit production were analysed by ANOVA using the mixed procedure with repeated measurements in SAS (SAS Institute Inc., 1993). Correlations between leaf biomass and number of basal sprouts, primary and secondary branches and stem basal area were explored.

5.3 RESULTS

5.3.1 Herbaceous-layer productivity

Two years after the trees had been introduced to the open grassland, no effects of treatments on the productivity of the herbaceous vegetation could be ascertained (Figure 5.1).

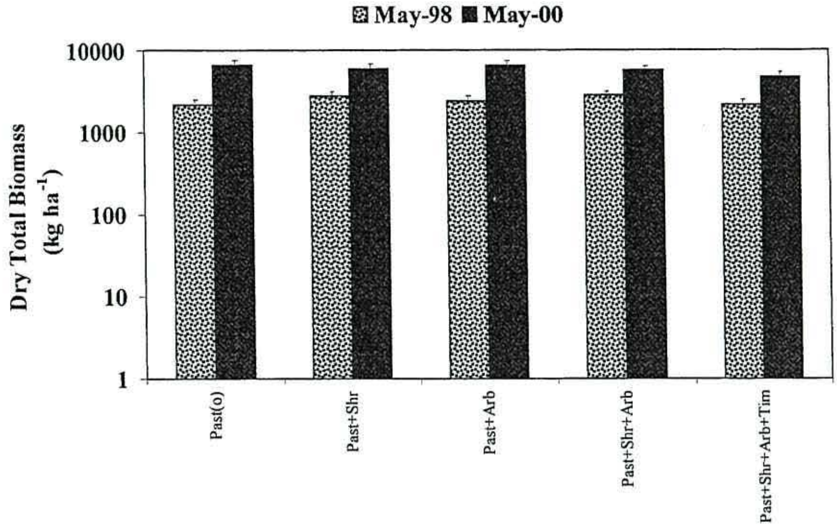


Figure. 5.1. Mean dry matter of herbaceous vegetation in different treatments in multistrata silvopastoral systems experiment with different levels of shrub and tree diversity at two sampling times. Means are back-transformed from natural logarithms.

Season had a highly significant effect (P=0.0001) on dry matter productivity of herbaceous vegetation, with significantly lower biomass during the dry parts of the evaluation period (Figure 5.2).

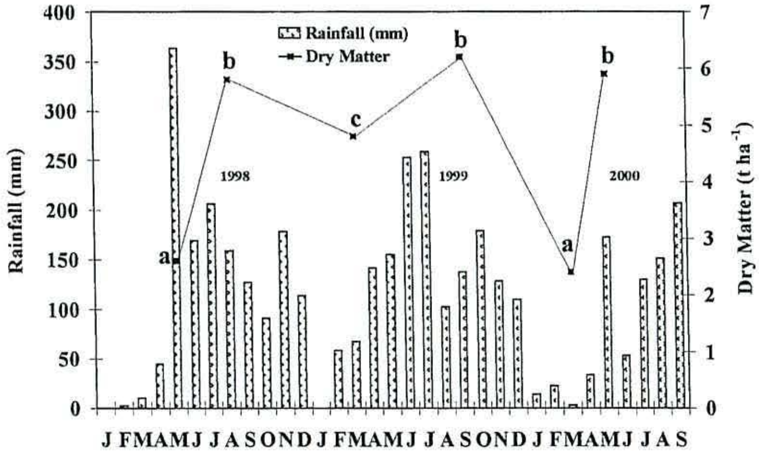


Figure 5.2. Monthly rainfall (bars) and the overall mean dry matter of herbaceous vegetation in multistrata silvopastoral systems experiment with different levels of structural complexity. Means followed by the same letter are not significantly different. Means are back-transformed from natural logarithms.

5.3.2 Herbaceous-layer composition

The composition of herbaceous vegetation before trees were established in May 1998 was fairly uniform across plots and dominated by grasses (mainly *Dichanthium aristatum*). In all treatments the percentage of grasses was between 68% and 82% and the remaining herbage comprised herbaceous legumes (9-18%) and undesirable species (7-16%).

The effects of season on herbaceous layer composition were highly significant (P=0.0001). As shown in Figure 5.3, the proportion of grass declined significantly (P=0.0001) in dry season 2000. The main factor contributing to this change in botanical composition appeared to be the presence of a hemipteran: insect *Alydidae*, identified by Dr. Joseph Schaeffner from Texas A&M Univeristy, as *Cydamus* sp. At the end of the wet season 1999, most plants of *Dichanthium aristatum* (the dominant grass in the experimental plots) were severely attacked. As a result of the decrease of grass species there was a significant increase of the proportion of herbaceous legumes and undesirable species in the dry season 2000 compared with the other evaluation periods. However, as the wet season 2000 progressed, the proportion of grass increased significantly, from 37% to 73%.

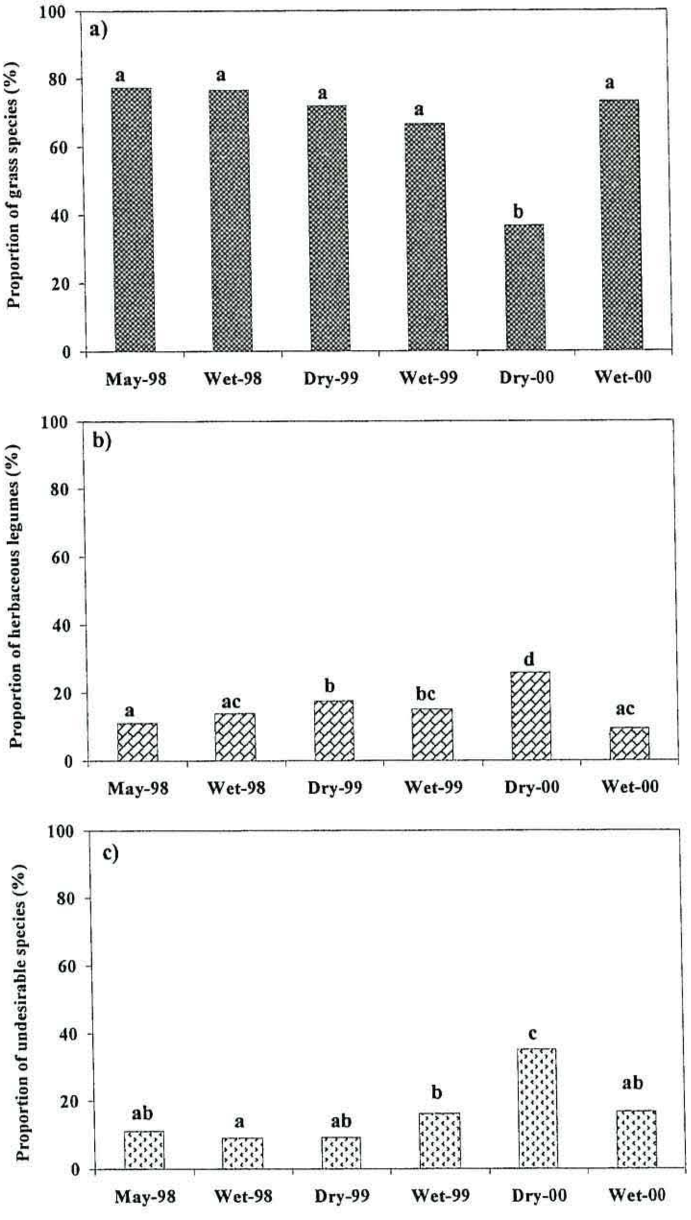


Figure 5.3. Means of botanical composition of herbaceous vegetation of silvopastoral systems with different levels of structural complexity. Means followed by the same letter within each component are not significantly different. Means back-transformed from arcsin. a) grass, b) legumes and c) undesirable species.

Paspalum conjugatum and *Ipomea hirta* were the undesirable species most abundantly found after the grass species started to decline. Both species were very aggressive and invaded most of the plots quickly. Therefore, a chemical control by spraying with a direct application of glyphosate for *Paspalum conjugatum* and 2, 4-diclorofenoxi for *Ipomoea hirta* was used.

5.3.3 Biomass of shrub species

Forage biomass here is defined as leaves, corresponding roughly to what might be eaten by browsing cattle.

5.3.3.1 Biomass per tree

Figure 5.4 indicates dry matter of forage biomass for each shrub species on a per tree basis in each treatment. *L. leucocephala* did not vary in relation to the different levels of structural complexity. Mean forage biomass of *G. sepium* was significantly higher (P=0.0001) in Treatment 4 than in Treatment 2. *C. cujete* had a significantly higher forage biomass in Treatment 5 than in Treatments 2 and 4 (P=0.0001). Overall forage biomass (mean of all three species) was also significantly higher in Treatment 4 than Treatment 2 (P=0.0023).

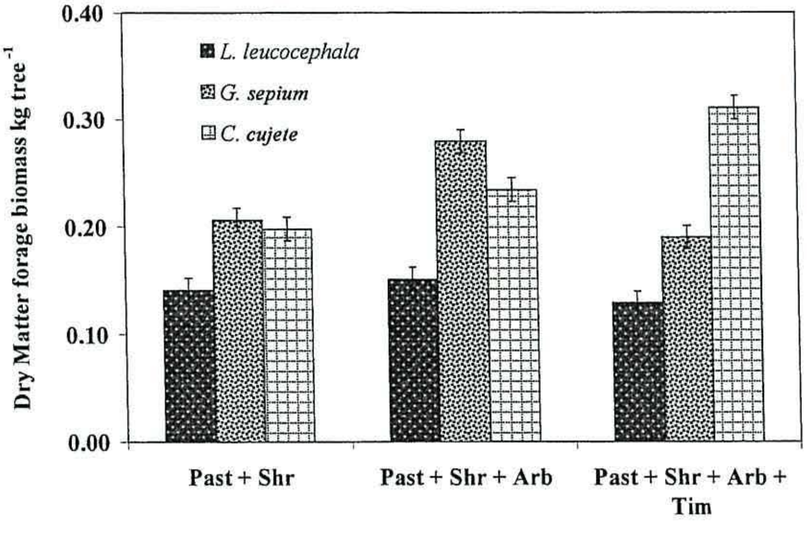


Figure 5.4. Mean dry matter biomass of shrub species at different levels of structural complexity in multistrata silvopastoral systems. Bars indicate standard errors.

5.3.3.2 Biomass per unit area

Treatment had a significant effect on forage biomass of shrub species on a per hectare basis (P=0.0001). Mean shrub forage biomass production per hectare over the whole measurement period (1999-2000) was significantly higher in Treatment 2 than in Treatments 4 and 5 (P=0.0001), where some shrubs had been substituted by arboreal and/or timber trees (Figure 5.5).

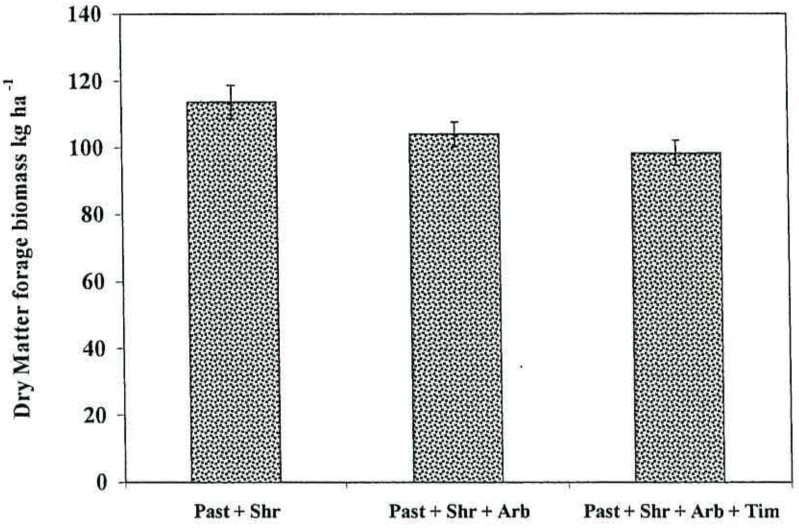


Figure 5.5. Mean standing forage biomass of shrub species per hectare in multistrata silvopastoral systems with treatments having different levels of tree diversity and structural complexity. Turipaná research centre, Cereté, Córdoba, Colombia. Bars indicate standard errors.

The interaction between treatment, species and evaluation period was highly significant (P=0.0001). In all treatments, a very slight decline in standing forage biomass per hectare of *Crescentia cujete* was observed between the first recording in February 1999 and the second evaluation in July 1999. However, subsequently there was a continual increase in standing forage biomass of *C. cujete* over time. There were significant differences between Treatment 5 and Treatments 2 and 4 in the forage biomass recorded at the end of the wet season in November 1999 and in the dry season of 2000. Forage biomass of *C. cujete* was much lower in both periods in Treatments 2 and 4 than in Treatment 5 (Figure 5.6a).

Forage biomass per hectare of *Gliricidia sepium* showed an initial decline after the first measurement in February 1999. In all treatments the highest leaf biomass of this species was observed at the end of the wet season (November 1999). Leaf biomass in Treatments 2 and 4 was higher than Treatment 5 (P=0.0001). In contrast to *C. cujete*, forage biomass of *G. sepium* decreased with the reduction in rainfall in the 2000 dry season (March 2000). This decrease was much higher in Treatment 5 than in Treatments 2 and 4 (Figure 5.6b).

Forage biomass per hectare of *Leucaena leucocephala* did not vary throughout the evaluation period or in relation to treatments except for a significantly higher forage biomass in November 1999. *L. leucocephala* biomass was much lower than that of the other two species in all treatments (Figure 5.6c)

The details of the correlation analysis relating forage biomass of the three shrub species to stem basal area are shown in Table 5.1. Stem basal area was significantly and positively correlated with forage biomass production throughout all measurement periods.

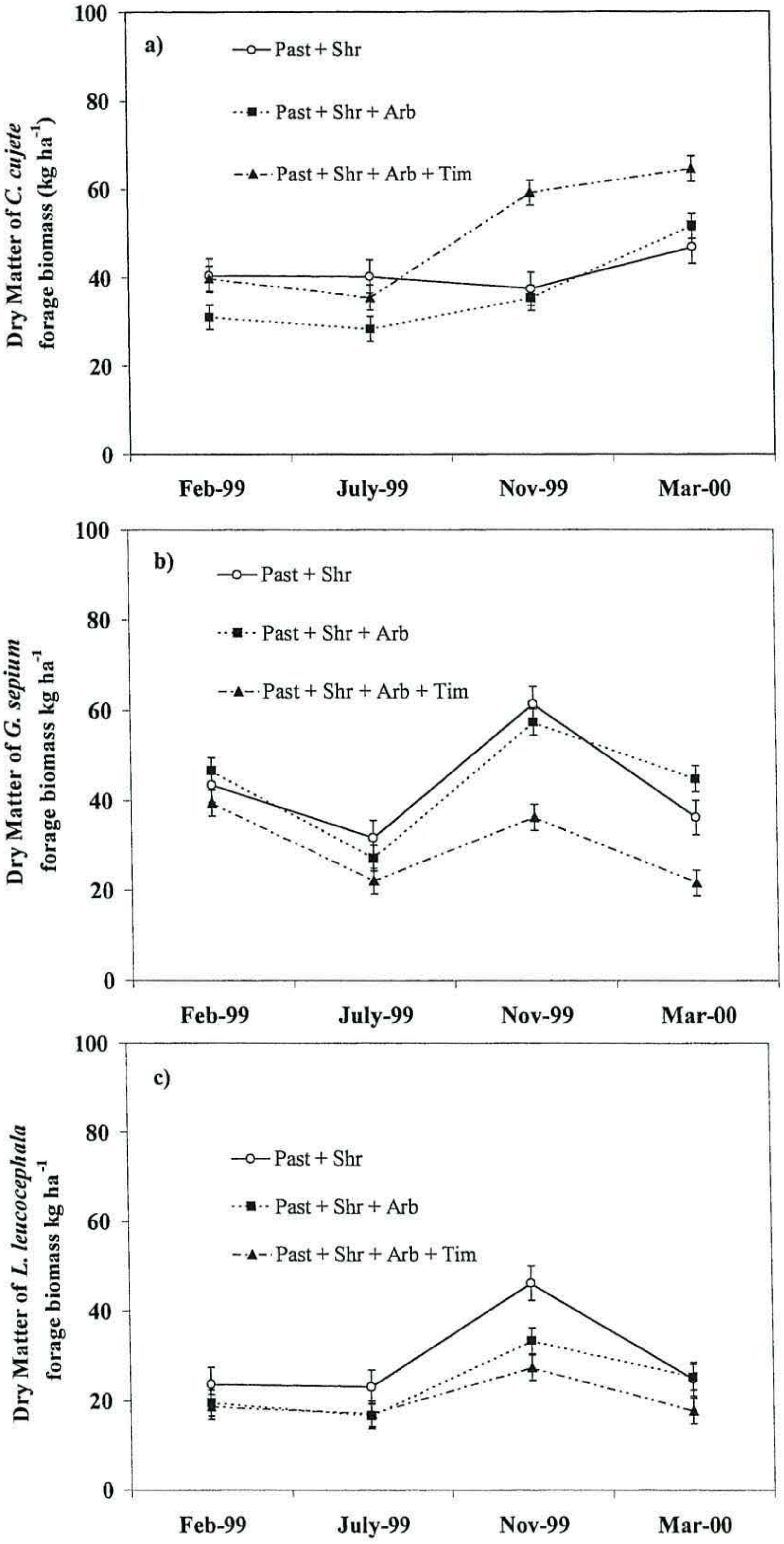


Figure 5.6. Mean dry matter biomass of shrub species per hectare at different periods in multistrata systems with different levels of structural complexity. a) *Crescentia cujete*, b) *Gliricidia sepium* and c) *Leucaena leucocephala*. Bars indicate standard errors.

5.1. Spearman's Product Correlations matrix of forage biomass (FB) and stem basal area (SBA) at different evaluation periods. Upper row is correlation coefficient, lower row p-value.

	February 99 FB	July 99 FB	November 99 FB	March 2000 FB
SBA (*C. cujete*)	0.7852	0.6066	0.7370	0.7636
	0.0001	0.0001	0.0001	0.0001
SBA (*G. sepium*)	0.6733	0.4326	0.4574	0.6072
	0.0001	0.0001	0.0001	0.0001
SBA (*L. leucocephala*)	0.5677	0.4869	0.7819	0.6914
	0.0001	0.0001	0.0001	0.0001

5.3.4 Branching

Primary branches were defined as those growing directly from the trunk and secondary branches as those coming off the primary branches (Huxley 1985).

Although the interaction between treatment and species was highly significant (P=0.0001), there was not a clear trend for primary branches. *Leucaena leucocephala* produced a similar number of primary branches in all treatments. *Crescentia cujete* had significantly fewer branches in Treatment 4 than in Treatments 2 and 5. *Gliricidia sepium* had significantly fewer primary branches in Treatment 5 than in Treatments 2 and 4. Similarly differences amongst species varied with treatment although *Leucaena leucocephala* had the smallest number of primary branches in all treatments and *Gliricidia sepium* had the highest in both Treatments 2 and 4, while *Crescentia cujete* had the most in Treatment 5 (Figure 5.7).

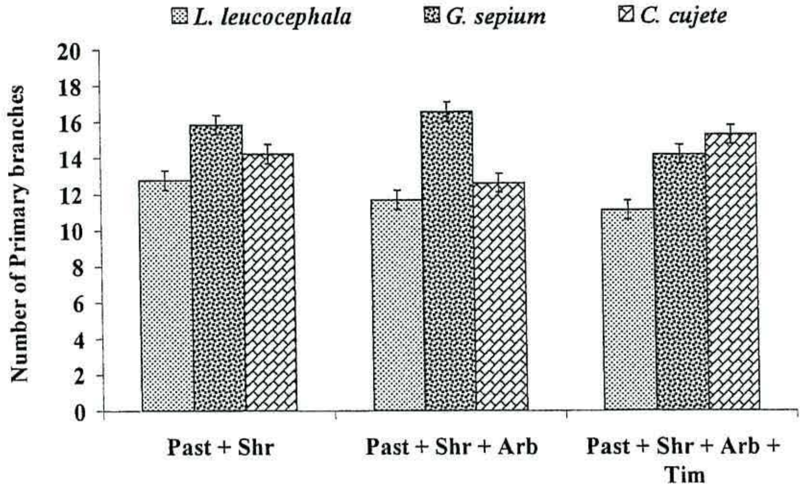


Figure 5.7. Mean number of primary branches per plant of shrub species in multistrata silvopastoral systems with different levels of diversity. Bars indicate standard errors.

There were markedly more secondary branches produced by *Gliricidia sepium* than the other two species (Figure 5.8). There were more subtle differences in the number of secondary branches in *Gliricidia sepium* across treatments with more in Treatment 4 than in Treatments 2 and 5.

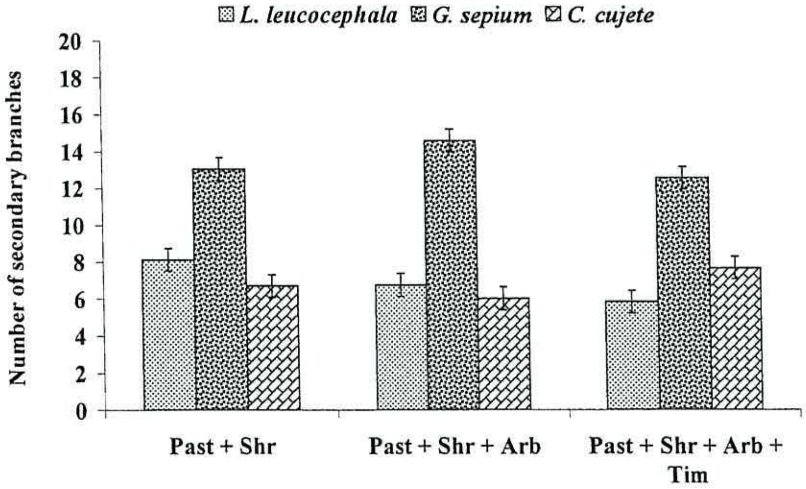


Figure 5.8. Means of secondary branches of shrub species of multistrata silvopastoral systems with different levels of diversity. Bars indicate standard errors.

5.3.5 Number of basal sprouts

Basal sprouts were defined as sprouts coming from the stem base. Treatment had no significant effect on the number of basal sprouts of the shrub species. The interaction between treatment and species clearly showed that *Gliricidia sepium* produced more basal sprouts, and significantly more in Treatment 4 than in Treatments 2 and 5. *Leucaena leucocephala* produced significantly fewer sprouts in Treatment 5 than in Treatments 2 and 4. No differences between treatments were found for *Crescentia cujete* (Figure 5.9).

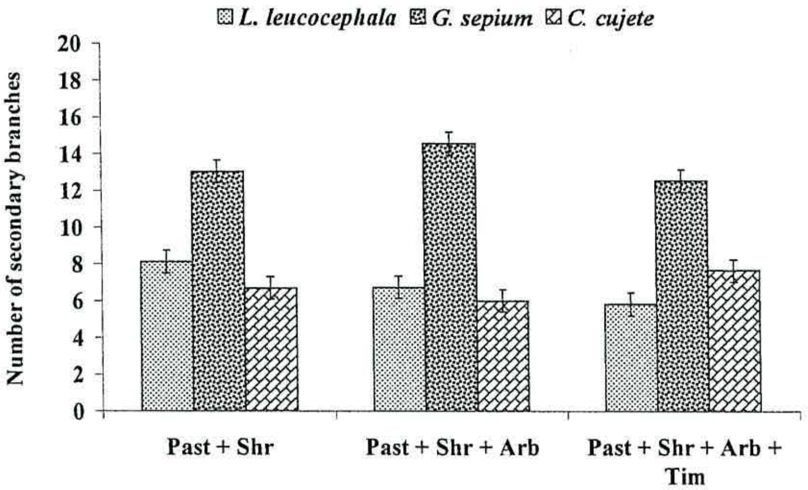


Figure 5.9. Means of number of basal sprouts of three shrub species of silvopastoral systems with different levels of diversity. Bars indicate standard errors.

5.3.6 Fruit production

Guazuma ulmifolia was the first species to produce fruits, seventeen months after planting. There was a significant effect of treatment on fruit production of *Guazuma ulmifolia* (P=0.0023). Treatment 5 had significantly higher production than in Treatments 3 and 4 (Figure 5.10).

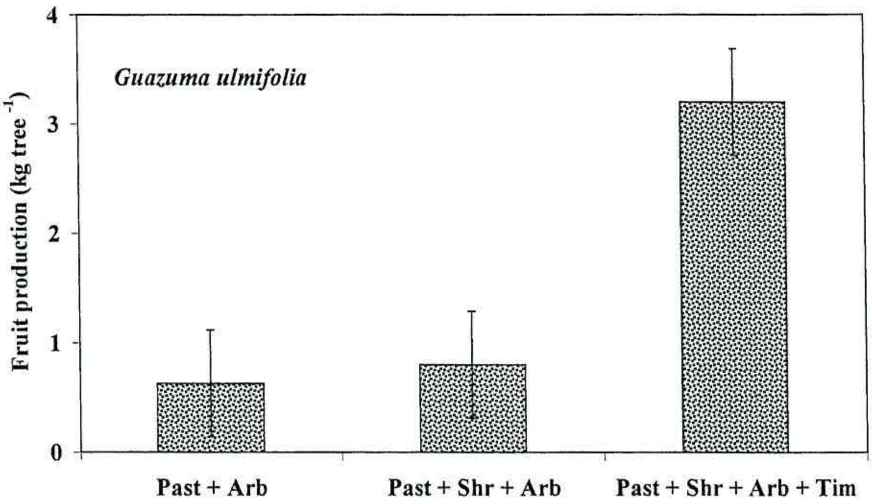


Figure 5.10. Means of fruit production of an arboreal species (*Guazuma ulmiflia*) of silvopastoral systems with different levels of shrub and tree diversity. Bars indicate standard errors.

5.4 DISCUSSION

5.4.1 Tree species and seasonal effects on pasture

The initial hypotheses that trees would i) reduce herbaceous biomass and ii) alter pasture composition, because of a predominance of competitive over facilitative interactions was not supported by the findings of this research. Fast growing trees of various species and types at an overall density of up to 625 trees ha^{-1} had no detectable effect on either pasture biomass or composition over a two year period. In contrast pasture biomass and composition were both heavily influenced by season with marked changes from the wet to the dry season. This demonstrates that high tree densities can be established in pasture in this environment without immediate reductions in pasture productivity.

When trees grow naturally or they are added to cultivated land there are a number of possible outcomes of the interactions between trees, crops and livestock (Anderson and

Sinclair, 1993). Plants growing in proximity to each other may utilise different resources so that there is little competition (complementarity) or interact in either positive ways (e.g. one plant shelters another), or negatively where one plant prevents another from occupying a portion of the habitat and exploiting the resources in it, which has been referred to as interference (Sanchez, 1995; Begon et al., 1990). Interference by trees is considered a major constraint in the integration of trees in grazed pastures (Somarriba, 1988; Jackson et al., 1990). The lack of an overall impact on understorey biomass of high densities of mixtures of up to nine different tree species on pasture in the present experiment may reflect either a high degree of complementarity in resource capture amongst tree and pasture species or that facilitative effects of trees on pasture outweighed competitive interactions. There are a variety of ways in which pasture may benefit from the presence of trees. Substantial evidence indicates that trees may improve soil conditions by fixing nitrogen, recycling water and nutrients from depth (Wilson et al., 1990; Sanchez, 1995; Young, 1997; Caldwell et al., 1998), reducing the impact of other competitors, and encouraging beneficial rhizosphere components or discouraging detrimental ones (Hunter and Aarssen, 1988). Sparse tree shade may also improve microclimate of pasture in seasonally dry environments by reducing evaporative demand (Smith et al., 1987).

In this study, three out of the nine tree species were nitrogen fixing legumes, two of the shrub species (*Gliricidia sepium* and *Leucaena leucocephala*) and one of the arboreals (*Albizia saman*). *Cassia grandis* is also leguminous but from a non-fixing genus. This means that in the treatments with a high overall tree density (625 ha^{-1}) over half (56-66%) the trees were capable of N-fixation and in Treatment 3 that only had the arboreal stratum and hence a much lower tree density (156 ha^{-1}), a third of the trees were of an N-fixing species. In general, N-fixing species could be expected to compete less for soil N with pasture (complementarity) than non-fixing species although the extent of N-fixation as opposed to uptake of soil N may vary in tree legumes according to field conditions and the fixation process is particularly sensitive to drought (Sprent, 1984). In addition, there could have been transfers of nitrogen from N-fixing trees to the pasture (facilitation). The shrubs were regularly defoliated (initially pruned and then browsed by cattle) which could stimulate nodule senescence and so make N available to the pasture (Rao and Giller, 1993) but the quantity of N transferred in this way may be smaller than through litterfall and/or manure and frequent defoliation may eventually suppress nodulation and nodule activity (Nygren, 1995; Snoeck, 1995). With respect to nutrients more generally, differences in root distributions could also lead to trees taking up nutrients from soil not exploited by pasture species (particularly at depth) and these then becoming available to pasture through litterfall and deposition of faeces and urine. The extent of niche separation for the tree-pasture combinations in the experiment is not known but some caution is required, since most of the nutrients, tree and pasture roots may all be in the surface soil, some pasture species may root deeply (Fisher et al., 1994) and since the trees were young, their root systems may not have developed an extensive network at depth.

In the multistrata treatments reduced evaporation from the soil surface as a result of crown shade may have conserved soil moisture availability, although trees that remain well foliated may also transpire a lot of water. Reductions of soil and plant water loss by tree crown shade through reduction of understorey temperature and evapotranspiration have been found by Smith et al. (1987). Wetlsin and Coughenour (1990) also found that, contrary to observations and models in which trees and herbaceous vegetation are viewed as competitors, trees in African savannas had positive impacts on herbaceous biomass production and composition. Their study found higher production of grass species below overlapping crowns (220 g m^{-2}) and under individual crowns (150 g m^{-2}), than in open areas between trees (95 g m^{-2}). Higher understorey productivity under tree crowns has also been found in other tropical ecosystems (Frost and McDougald, 1989; Belsky et al., 1989; Belsky et al., 1992, 1994; Amundson et al., 1995), and the authors have suggested that may be due to the ameliorating influence of shade in hot, dry environments and to increases in soil fertility under the tree crowns.

5.4.1.1 Effects of season

Annual herbaceous productivity in arid and semi-arid grasslands and savannas is directly related to annual rainfall (Robertson, 1988; Scholes, 1990), with productivity increasing both along geographic gradients of increasing rainfall, and also in years of higher rainfall (Amundson et al., 1995). Consistent with findings in the single tree plot study (Chapter 3), and as expected, season was the main factor affecting pasture biomass. Total standing dry matter varied according to the amount of rainfall, being on average 1.2 t ha^{-1} higher in the wet season than in the dry season.

The species composition also changed markedly from the wet season in 1999 to the dry season in 2000, when the proportion of grasses reduced by approximately 50% (Figure 5.3) in both multistrata treatments and control plots. The proportion of grasses started to decline in the wet season 1999, and this decline was more dramatic in the evaluation recorded in the dry season 2000, when dry matter of the grass species reduced from 3.7 t ha^{-1} (wet season 1999) to 0.8 t ha^{-1} (dry season 2000). At the end of the wet season in 1999, *Dichanthium aristatum,* the dominant grass in the experimental plots, was severely attacked by *Cydamus sp.* that affected the growth and re-growth of pasture biomass.

5.4.2 Forage biomass of shrub species

As there was no decrease in pasture biomass attributable to trees, the substantial forage biomass of shrub species represents a net increase in total forage biomass available as a result of adding trees to pasture, affirming the third hypothesis that overall forage biomass would be increased by introducing trees to pastures.

The different shrub species responded differently in terms of their seasonal pattern of biomass and to the substitution of some shrubs with arboreal and/or timber trees. The trend of forage biomass per tree was consistent with previously reported trends in their basal area (see Chapter 4, Figure 4.4), and there was a strong positive correlation between basal area and forage biomass for all three species throughout all evaluation periods. Both *C. cujete* and *G. sepium* had higher forage biomass in Treatments 4 and 5 where some shrubs had been substituted with arboreal or timber trees than in Treatment 2. As discussed previously in Chapter 4 Section 4.2.2.2.1, this is possibly because substitution of shrubs with other trees reduced competition amongst plants in the shrub layer, because of greater niche separation or complementarity of resource use between shrubs and other tree species rather than amongst shrubs themselves. As the experiment progressed, the shrubs (which were maintained at a height of <1.2 m), may have been shaded to some extent by arboreal and/or timber trees that were free growing and differences in shade tolerance as well in niche separation with respect to below ground resources with arboreal and timber species, may explain why different shrub species responded differently to treatments.

It is important to stress that despite the fact that *G. sepium* is drought-deciduous, and there was evidence of seasonality effects, this shrub still contributed a considerable amount of forage biomass in the dry season. *L. leucocephala* appeared not to be affected by shade levels, and its lower overall biomass may possibly be explained in terms of competition, especially for water. The results of water use discussed in Chapter 3 indicated that *L. leucocephala* used significantly more water per unit leaf area than *Gliricidia sepium* and *Guazuma ulmifolia*, which could also explain the low *L. leucocephala* forage biomass in March 2000. Care must be taken however in interpreting the standing forage biomass measurements since the change in biomass between consecutive measurement times represents a balance between growth during the period since the previous assessment and any litterfall or utilisation by browsing animals. Thus, the high biomass of *Crescentia cujete* could reflect higher leaf retention or low palatability to cattle, as well as fast growth. Studies of the nutritional quality (Chapter 6) and voluntary browse intake by cattle (Chapter 6) reported later, however, indicate that all shrubs were eaten by cattle.

Although highest forage biomass in the three shrub species was achieved in the second period of the wet season of 1999, in terms of animal production the most important factor is the availability of forage biomass during the time when pasture biomass is most scarce (the dry season). Six months after establishment (February-March 1999), dry matter of forage biomass was around 100 kg ha^{-1}. Although forage biomass at twenty-two months (February-March 2000) was somewhat lower than that at the end of the previous wet season, the results indicate that shrub species maintained reasonable levels of forage biomass production despite the reduction in rainfall, while grass biomass was

3.0 t ha^{-1} less at the end of the dry season than in the wet season. It is likely that cattle would rely more heavily on shrub forage in the dry season.

Amongst the arboreal species, only *Guazuma ulmifolia* produced fruits during the evaluation period, seventeen months after planting, and there was a significant effect of treatment on fruit productivity in line with the overall size of the trees. There was a much higher fruit production (2 kg tree^{-1} more) in Treatment 5 than in the other two treatments (3 and 4). Trees of *G. ulmifolia* in Treatment 5 were significantly larger in terms of basal area than trees of the other two treatments; but there were only significant differences in height in relation to Treatment 3 (see Chapter 4 Figures 4.5 and 4.9). Bertiller et al. (1991) found that the timing of phenological events in arid zone shrubs depended primarily on the depth of root systems and access to soil moisture and nutrients. Flowering and fruiting of *Acacia aneura*, *Acacia estrophiolata* and *Acacia kempeana* were strongly influenced by soil moisture. It is possible that higher fruit production in Treatment 5 was associated with better access by *Guazuma ulmifolia* trees to soil moisture and nutrients than in Treatments 3 and 4 but this is unlikely since a larger difference might have been expected between Treatment 3 and 4 (where 469 shrubs ha^{-1} are added) than between Treatments 4 and 5 (where the difference is that 39 arboreal trees have been substituted by timber species but the overall tree density has remained the same).

The objective of this study was to explore the potential contribution that shrub species could make in terms of forage biomass as a supplement to pasture, especially during the dry season, when pasture biomass is scarce and of low nutritional quality. The results indicate that shrubs can be established on pastures at densities that permit substantial contributions of tree forage biomass without reducing pasture production. Furthermore, shrub species appear to differ in how much forage biomass they carry in the dry season, with *Crescentia cujete* appearing to have more complementary phenology with pasture grasses than either *Gliricidia sepium* or *Leucaena leucocephala*. Assessing the full potential role of these shrubs in cattle feeding systems in the Caribbean region requires exploration of their nutritional quality, which is investigated in the next chapter.

CHAPTER 6

NUTRITIONAL CHARACTERISTICS OF SHRUB, ARBOREAL AND HERBACEOUS SPECIES IN DIVERSE SILVOPASTORAL SYSTEMS

6.1 INTRODUCTION

The use of shrub and arboreal browse species is being encouraged to supplement low quality grasses, which comprise most of the diet of ruminants in the Caribbean region of Colombia. Production systems are mainly extensive, and cattle graze on both natural and improved pasture (CORPOICA, 2000). *Dichanthium aristatum*, *Brachiaria mutica*, *Panicum maximum* and *Bothriochloa pertusa* are the dominant grass species. These species are characterised by low protein content and poor digestibility. Laredo (1987) and Cuadrado et al. (1996) found values of crude protein ranged from 4.5 to 7.1% during the dry season, and 3.9 to 9.1% in the wet season. Degradability of dry matter has been found to be around 57 g 100 g^{-1} DM (LC Arreaza, unpublished data). In the present chapter information about nitrogen and tannin contents, as well as degradability, of dry matter of different pasture and tree species is provided. Specific attention is given to feed intake, which constrains animal production as a result of pasture scarcity during the dry season and could be improved by the introduction of browse species to pastures or intensification of tree cover on farms where some trees are already present on pastures.

Nutrition, particularly during the dry season, is commonly seen as the major constraint to animal production in the Caribbean region (Cajas-Girón and Sinclair, 2001). The low protein content of pasture means that cattle do not consume sufficient digestible nutrients, suffer imbalances in rumen fermentation and receive a deficient flow of nutrients to the duodenum (Leng et al., 1992, Ørskov, 1995). Livestock production may be improved by researching and identifying new and high quality, but cheap, feed resources. Browse species may have a role here, generally having a higher nutritive value than grasses, and being superior in terms of protein and mineral content as well as in their leaf biomass productivity (Aletor and Omodara, 1994).

The nutritional quality of trees and shrubs varies according to the species. In general, the nitrogen contents of tree leaves are much higher than grasses, even at times of year when grass growth is vigorous (Aletor and Omodara, 1994). Whereas grasses and other herbs have reduced productivity or may die when upper soil layers lose their moisture, deep-rooted trees may exploit soil moisture at depth and continue to grow; therefore during the dry season or at times of drought, trees provide forage rich in protein, minerals and vitamins, while herbaceous cover provides only poor quality straw (Gutteridge and Shelton, 1994). The leaves, flowers and fine stems comprise the edible components of browse species, and fruits in particular are a valuable source of protein and energy for livestock during dry periods. But since fodder trees are mostly offered as a supplement to a basal diet, their nutritional value depends on how well they complement the value of the basal diet to provide a range of nutrients required by the animal for their maintenance, growth, production and reproduction (Gill et al., 1992; Norton, 1994). There is considerable variation amongst trees with respect to nutritive value; variations occur even within species due to differences in plant parts, age, tissues, climatic and cultural conditions (as trees may be affected by season and the stocking rate or cutting interval), and how fodder has been harvested (Gutteridge, 1995; Upadhyay, 1995; Perera, 1995). All components of nutritive value change markedly along a leafy shoot as young leaves expand, mature and begin to senesce (Minson, 1990; Khazal et al., 1993).

Nutritive value is a function of feed intake and the efficiency of extraction of nutrients from the feed during digestion (Norton, 1994). Browse species can influence animal nutrition either directly, through provision of fodder from their leaves or fruits, or indirectly through effects on the understorey pasture (Robinson, 1985). Multipurpose forage trees are increasingly being used as a source of nutrients for ruminants in attempts to achieve sustainable systems of animal production. However, not much is known about their nutritive value, and there is little information on feed intake for complex diets containing browse and herbaceous species. Most of the information that is available on feed intake of tree fodder species has been estimated using housed animals, mainly in metabolic crates, while most research on feed intake in field situations has been carried out only for simple biomass (sown grass), which can be easily measured, though all measurement methods have limitations (Dove and Mayes, 1996). In studies of diets where browse species are combined with grazed species, diet composition and dry matter intake of the forage available to large ruminant animals are important variables that may determine whether animals have an unbalanced diet, which could contribute to disturbances in their productive or reproductive status. A better understanding of the nutritive value of tree and shrub fodder is an important step in designing more appropriate feeding systems for sustainable animal production systems in the tropics. The overall aim of the research reported in this chapter was to evaluate the nutritive value of browse in diverse silvopastoral systems, the specific objectives were as follows.

- To measure the nutritive value of a variety of browses species that may be used in developing silvopstoral systems in the Caribbean region of Colombia.
- To investigate whether there are interactions amongst plant species in terms of: nutritive value, and
- rumen function when components are grown together and when complex diets are eaten by cattle.
- To estimate voluntary feed intake of browse species by milking cows and to evaluate whether the *n*-alkane technique could be used to measure diet composition and feed intake of complex diets including several browse species.

6.2 METHODOLOGY

6.2.1 Sampling for nutritional analyses

Samples of three shrub (*Crescentia cujete*, *Gliricidia sepium* and *Leucaena leucocephala*) and three arboreal species (*Albizia saman*, *Cassia grandis* and *Guazuma ulmifolia*), two grasses (*Dichanthium aristatum* and *Brachiaria mutica*) and the most frequently occurring herbaceous legumes (*Centrosema pubescens*, *Desmoidum uncinatum*, *Rhynchosia minima*, *Teramnus uncintus* and *Vigna sp.*) found in the plots in all treatments of the multistrata silvopstoral systems experiment described previously (Section 4.2.2) were collected manually by following the grazing-browse route taken by cows through the plot, and collecting only samples of the parts of the plants that cattle were actually eating. The species were sampled once in the wet and once in the dry season. Aproximately 3 kg of fresh material per species were collected. The fresh material of each species was mixed and a subample of 100 g of fresh sample was deep frozen for tannin analysis; the remaining material was oven dried and ground for the other nutritional analyses.

6.2.1.1 Nitrogen content

Samples to determine nitrogen content were oven-dried to a constant weight of 60°C. Dried herbage samples were ground through hammer mills fitted with a 1 mm mesh sieve. Samples were taken to the soils laboratory of the School of Agricultural and Forest Sciences, University of Wales, Bangor and nitrogen content was determined using a CHN-2000 Elemental analysis Version 2.0 (LECO Corporation, St Joseph, Michigan).

6.2.1.2 Tannin content

Samples for estimation of condensed tannin content were frozen and taken to the Nutrition Laboratory of Corpoica in Tibiatatá Research Centre. Samples were oven dried at 60°C for 48 hours then ground using a through a hammer mill (Thomas Wiley, model 3) fitted with 1 mm mesh sieve. Tannin contents were determined using the vanillin-HCl method (Harris, 1970).

6.2.1.3 Dry matter degradation

Four Brahman heifers with rumen fistula were used to evaluate dry matter degradation of the shrubs, arboreals, grasses and herbaceous legumes in the wet season 1999 and the dry season 2000.

Rumen degradability of each species was determined using the nylon bag technique (Mehrez and Ørskov, 1977). Oven-dried samples were milled through a hammer mill to pass a 2 mm screen and 3 g were weighed into nylon bags (14 x 20 cm with 40 µ pore size manufactured by the International Food Resources Unit, Aberdeen, UK). Bags were placed in the rumen in a mesh bag and anchored with about 70 cm of nylon cord to the cannula top to allow the bags to move freely within the digesta. Additional weights were attached to the bags to ensure that they did not float on top of the rumen contents. Bags were withdrawn after incubation periods of 8, 12, 24, 48 and 72 hours. After incubation the bags were hand washed and dried for 48 hours at 60°C. Zero time washing losses were estimated by soaking two bags per sample in warm tap water (37°C) for one hour followed by washing and drying as stated above. During the evaluation period the fistulated heifers grazed the experimental plots so that they were eating the same diet for which the results were to be applied. For each combination of species, incubation time and plot there were four replicated samples each incubated in different heifers.

The same procedure was applied in both the wet (1999) and the dry season (2000).

6.2.1.4 Rumen ammonia nitrogen

Three Brahman heifers with rumen fistula were sampled for rumen fluid within each agroforestry treatment and the open grassland control, in the last three days from 10-day grazing period to avoid the carry-over residual effects of the previous treatment. Rumen fluid was collected every two hours from 5:00 to 19:00, and each heifer at each time was sampled three times. The three samples of the rumen fluid collected at each time were stored in plastic bottles into which was added 1 ml of sulphuric acid at 50% dilution as a preservative. The rumen fluid samples were deep frozen immediately after each sampling time and stored at –15°C pending ammonia nitrogen analysis.

Rumen fluid concentration (NH_4) was determined in Kjeldahl digest by an automated procedure (Crooke and Simpson, 1971).

6.2.2 Use of *n*-alkanes to estimate feed intake of browse species

A pilot study on the feasibility of using the *n*-alkane technique to measure feed intake of several browse species in a complex diet was done in a plot containing pasture and three shrub species (treatment 2 of the multistrata experiment described in Chapter 4). The pasture comprised mainly *Dichanthium aristatum* and herbaceous legumes and there were three shrub species (*Crescentia cujete*, *Gliricidia sepium* and *Leucaena leucocephala*), each at a density of 208 plants ha^{-1}. Five milking Holstein x Zebu cows grazing this site were dosed twice-daily with paper pellets impregnated with 279 mg dotriacontane (C_{32}) over a ten-day period in March 2000 (dry season). The cows had an average daily milk yield of 5.5 kg and average live weight of 450 kg. Milking occurred once daily; the cows were dosed once in the morning after milking (07:30 am) and in the afternoon (15:00). During the last five days of the dosing period, faecal grab samples were taken from each animal after the morning and afternoon dosing. These samples were kept separately for each animal. Ten samples were, therefore, generated for each cow.

Samples of two grass species (*Dichanthium aristatum* and *Brachiaria mutica*), five herbaceous legumes (*Centrosema pubescens, Desmodium uncinatum*, *Teramnus uncinatus*, *Rhynchosia minima* and *Vigna sp.*) and of the three shrub species were collected manually by following the cows and sampling a similar fraction of the plant as grazed or browsed by the cows. Forage and faeces samples were dried at 60° C to a constant weight. Dried faecal and herbage samples were ground through hammer mills fitted with a 1 mm mesh sieve. Samples of herbage and faeces were taken to the Macaulay Land Use Research Institute (MLURI) in Aberdeen (UK) to determine *n*-alkane concentration.

The alkanes were extracted from 0.1 g dried faeces and 0.2 g dried herbage using the modification described by Salt *et al.* (1992), of the method of Mayes *et al.* (1986a). The equipment used was a Unicam PU 4500 Gas Chromatograph (GC) fitted with a flame-ionisation detector. The column Supelco, a SPB-1 bonded phase gas column, was 30 m long x 0.75 mm i.d. glass with a film thickness of 1 μm. Data were captured on a Thermo-separations Chromjet Integrator and transferred to a computer via Spectra-

Physics "Labnet" Software. Data were processed using Spectra-Physics "Winner" software followed by Microsoft Excel. The plant species composition of the diet was estimated from the patterns of alkanes found in the faeces and in the dietary plants using a least-squares optimisation routine (Excel Solver); the algorithm selected dietary plant proportions such that the sum of the squared discrepancies between the actual faecal alkane concentration (corrected for incomplete recovery), and the calculated concentration was minimised. After calculating the C_{32} and tritriacontane (C_{33}) concentrations of the whole diet of each cow, feed intake was calculated using the equation described by Mayes *et al.* (1986a).

6.2.3 Statistical analyses

6.2.3.1 Protein and tannins

Using a mixed procedure in SAS (SAS Institute Inc., 1992), the following statistical model (Equation 6.1) was used for the analyses of nitrogen and tannin content. Both variables were expressed in g kg^{-1} DM.

$$Y_{ij} = \mu + T_i + Sp_j + S_k + TSp_{ik} + SpS_{jk} + E_{ijk} \qquad \text{Equation 6.1}$$

Where:

Y_{ij} = g of N or tannins (kg^{-1} DM)

μ = mean

T_i = Treatment effect

Sp_j = Species effect

S_k = Season effect

TSp_{ij} = Interaction between treatment and species

SpS_{jk} = Interaction between species and season

E_{ijk} = Residual error

6.2.3.2 Dry matter degradation

The disappearance of dry matter from the nylon bag was fitted to the exponential model (Equation 6.2; ∅rskov and McDonald 1979) using the 'fcurve' program.

$$p = a + b\ (1\text{-}e^{-ct}) \qquad \text{Equation 6.2}$$

Where:

p = Dry matter disappearance at time t
a = Rapidly soluble fraction
b = Amount which in time will degrade
c = Fractional rate constant at which the fraction described by b will be degraded per hour.

The constants of the fitted curve of dry matter degradability and data of the incubation times were analysed using a mixed procedure in SAS. Correlation analyses were used to ascertain the relationship between effective degradability, nitrogen and condensed tannin content. Regression analyses were used to establish relationships between effective degradability and nitrogen and condensed tannin content using SAS (SAS Institute Inc, 1992).

6.2.3.3 Rumen ammonia nitrogen

Data of rumen fluid were analysed using a mixed procedure in SAS (SAS Institute Inc., 1992) to investigate the effects of treatment and season Equation 6.3).

$$Y_{ij} = \mu + T_i + S_j + TS_{ik} + E_{ij} \quad \text{Equation 6.3}$$

Where:

Y_{ij} = mg of ammonia per litre

μ = mean

T_i = Effect of treatment

S_j = Effect of season

TS_{ik} = Effect of the interaction treatment and season

E_{ij} = Residual error

6.2.3.4 Analysis for feed intake

Differences in the amount of daily feed consumed by each cow for each shrub species were assessed using a t-test procedure (SAS Institute Inc, 1992).

6.3 RESULTS

6.3.1 Nitrogen (N) content

6.3.1.1 Shrub species (*Crescentia cujete*, *Gliricidia sepium* and *Leucaena leucocephala*)

As expected, shrub species differed in their nitrogen content. *C. cujete* had significantly (P=0.0001) lower nitrogen content than the other two species in both seasons, *G. sepium* had significantly lower (P=0.0001) nitrogen content in the dry season than in the wet season (46 g kg^{-1} DM and 38 g kg^{-1} DM in the wet and dry season respectively). There were significant differences (P=0.0001) between *L. leucocephala* and *G. sepium* in the dry season (Figure 6.1).

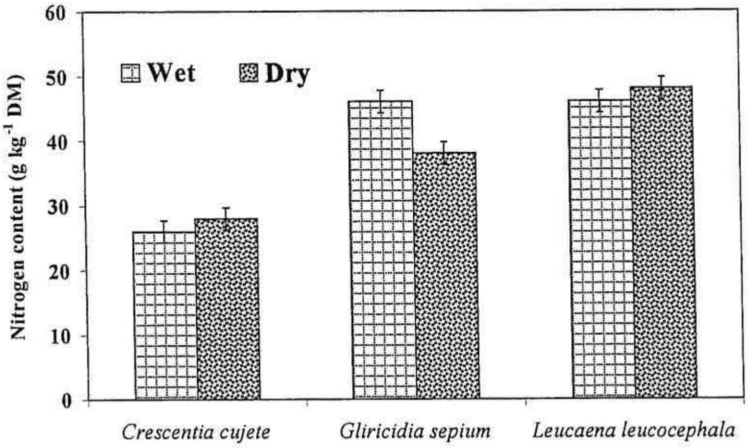


Figure 6.1. Means of nitrogen content of edible parts of three shrub species harvested in the middle of the wet (August) and dry (February) seasons, in multistrata silvopastoral systems experiment with different levels of diversity and structural complexity. Bars indicate standard errors.

6.3.1.2 Arboreal species (*Albizia saman*, *Cassia grandis* and *Guazuma ulmifolia*)

There were no effects of season on nitrogen content of arboreal species, but there were large differences amongst species. *A. saman* had much higher nitrogen content than *C. grandis* and *G. ulmifolia* (40 g kg^{-1} DM compared with the overall nitrogen content 27 and 25 kg^{-1} DM) (Figure 6.2).

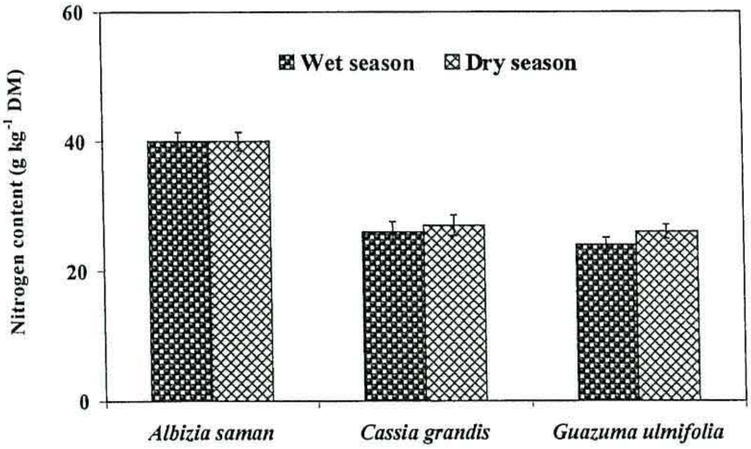


Figure 6.2. Means of nitrogen content of edible parts of three arboreal species harvested in the middle of the wet (August) and dry (February) seasons, in multistrata silvopastoral systems experiment with different levels of diversity and structural complexity. Bars indicate standard errors.

6.3.1.3 Grasses and legumes (*Dichanthium aristatum, Brachiaria mutica, Centrosema pubescens, Desmodium uncinatum, Rhynchosia minima, Teramnus uncinatus* and *Vigna sp.*)

There was a clear tendency for nitrogen content of herbaceous species to decrease from the wet to the dry season (P=0.0001, Figure 6.3). Significant differences between the two seasons were found for both grass species and for legumes such as *C. pubescens*, and *R. minima* (P=0.0001). Nitrogen content for the two grass species was significantly lower than herbaceous legumes in both the wet and the dry seasons (P=0.0001). *D. aristatum* in both wet and dry seasons had lower nitrogen content than *B. mutica*. Amongst legume species, *C. pubescens* and *Vigna sp.* had higher nitrogen content in the wet season than the other legume species. In the dry season *D. uncinatum* and *R. minima* had much lower nitrogen content than the other species.

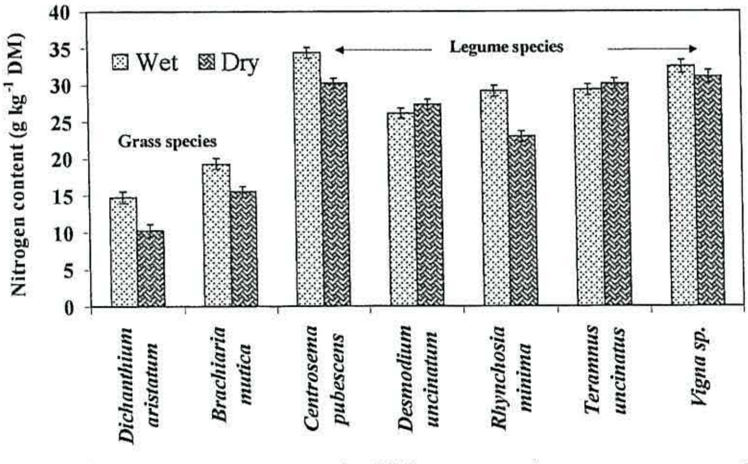


Figure 6.3. Means of nitrogen content of edible parts of two grasses and five herbaceous legume species harvested in the middle of the wet (August) and dry (February) seasons, in multistrata silvopastoral systems with different levels of diversity and structural complexity. Bars indicate standard errors.

6.3.2 Condensed tannin content (Proanthocyanidins)

6.3.2.1 Shrub species (*Crescentia cujete*, *Gliricidia sepium* and *Leucaena leucocephala*)

Tannin levels in the shrub species were highest for *Leucaena leucocephala* (37 g kg^{-1} DM), intermediate in *G. sepium* (24 g kg^{-1} DM), and lowest in *C. cujete* (14 g kg^{-1} DM) ($P=0.0003$). The interaction between species and season was also significant ($P=0.0358$). *L. leucocephala* had 50% lower condensed tannin levels in the dry season compared with the wet. Tannin levels of *L. leucocephala* were significantly higher than *C. cujete* in both seasons ($P=0.001$), but there were no significant differences between the tannin levels of *L. leucocephala* and *G. sepium* in the dry season (Figure 6.4).

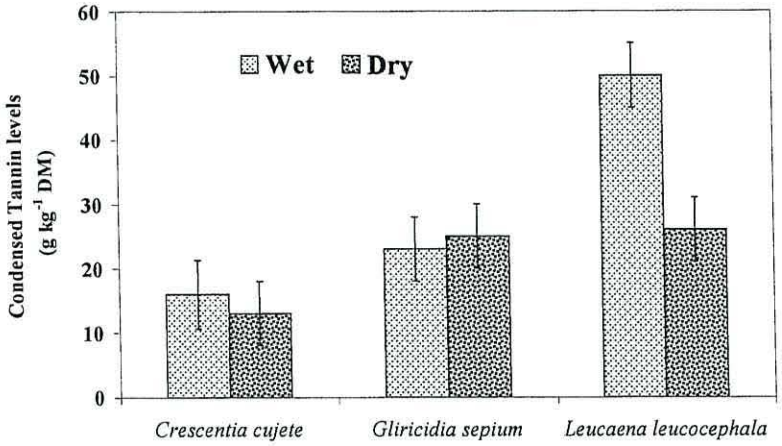


Figure 6.4. Means of tannin content of edible parts of three shrub species harvested in the middle of the wet (August) and dry (February) seasons, in multistrata silvopastoral systems experiment with different levels of diversity and structural complexity. Bars indicate standard errors.

6.3.2.2 Arboreal species (*Albizia saman*, *Cassia grandis* and *Guazuma ulmifolia*)

There were no effects of season on tannin levels in the arboreal species. Figure 6.5 indicates how tannin levels varied according to species (P=0.0001*)*. Overall mean for the three arboreal species showed that *C. grandis* had higher levels (134 g kg^{-1} DM) than *A. saman* (25 g kg^{-1}DM) and *G. ulmifolia* (18 g kg^{-1}DM) (Figure 6.5).

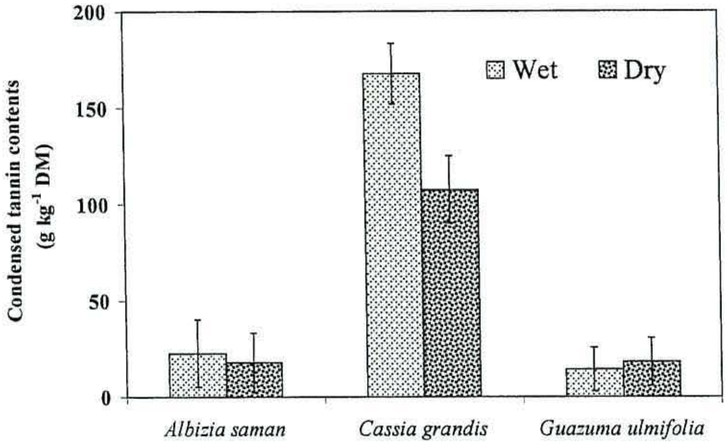


Figure 6.5. Means of tannins content of edible parts of three arboreal species harvested in the middle of the wet (August) and dry (February) seasons, in multistrata silvopastoral systems experiment with different levels of diversity and structural complexity. Bars indicate standard errors.

6.3.2.3 Herbaceous legumes (*Centrosema pubescens, Desmodium uncinatum, Rhynchosia minima, Teramnus uncinatus* and *Vigna sp.*)

Season had a significant effect (P=0.0001) on tannin levels in herbaceous legumes, with the overall mean showing a decline from the wet to the dry season by 33%, but there was no interaction between season and species. Overall mean for tannin contents of legumes varied from 18 g kg^{-1}DM (*Centrosema pubescens*) to 30 g kg^{-1} DM (*Desmodium uncinatum, Rhynchosia minima* and *Vigna sp*). Intermediate levels of condensed tannins were observed in *Teramnus uncinatus* (24 g kg^{-1}DM) (Figure 6.6).

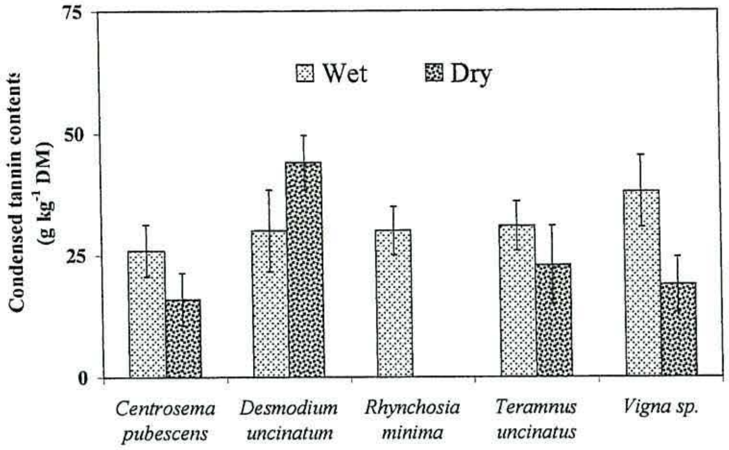


Figure 6.6. Means of tannins content of edible part of and five herbaceous legumes species harvested in the middle of the wet (August) and dry (February) seasons, in multistrata silvopastoral systems with different levels of diversity and structural complexity. Bars indicate standard errors.

6.3.3 Dry matter degradability

6.3.3.1 Effects of treatment and season on shrub species *(Crescentia cujete, Gliricidia sepium* and *Leucaena leucocephala)*

There were no significant effects of treatment or season on dry matter degradability or any of its components in *C. cujete*, except for the fractional-degradation rate constant *c*, which was significantly higher in the wet season (c = 0.09) than in the dry season (c = 0.06). The fitted curve showing disappearance of dry matter over time shows that *C. cujete* appeared to be less degradable than *G. sepium* but more degradable than *L. leucocephala* (Figure 6.7a).

Parameters of degradability of *G. sepium* did not vary according to treatment either. Effects of season were significant on fractional-degradability rate constant (*c*) (P=0.031), potential degradability (PD = a+b), and disappearance of the dry matter in the rumen (P=0.0001). Fractional-degradability rate constant (*c*) was significantly higher in the wet season (c = 0.21) than in the dry season (c = 0.05). Potential degradability was significantly higher in the wet (71 g 100 g^{-1} DM) than in the dry season (68 g 100 g^{-1} DM). Pronounced differences between season were observed in dry matter disappearance in the rumen for *G. sepium* (Figure 6.7b). In the wet season more than 60% of dry matter disappeared within the first 8 hours, and more than 80% was degraded at 72 hours; while in the dry season less than 50% was degraded within the first 24 hours, and at the end of the incubation time (72 hours) the amount which had disappeared from the rumen was around 60%.

Disappearance of the dry matter from the rumen at 72 hours and potential degradability of *L. leucocephala* were significantly lower when it was associated with pasture only than when growing with other shrub, arboreal and timber species (Table 6.1).

Seasonal effects on *L. leucocephala* degradability characteristics of dry matter are given in Table 6.2. Large differences were observed in the soluble fraction (*a*), the insoluble but fermentable fraction (*b*) and the fractional-degradability rate constant (*c*), between the wet and dry seasons. Potential degradability was significantly higher (P=0.0113) in the dry season than in the wet season. Dry matter disappearance in the rumen was only affected by season in the first two incubation times. At 8 and 12 hours *L. leucocephala* degraded more rapidly in the wet than in the dry season (Figure 6.7c).

Table 6.1 Mean values of the effects of treatments on degradation of dry matter of *Leucaena leucocephala*, in nylon bags incubated for 8-72 hours in multistrata silvopastoral systems experiment with different levels of structural complexity at Turipaná, Córdoba, Colombia. Means within the same column with different subscript letters are statistically different at p<0.05.

Treatments	8 h	12 h	24 h	48 h	72 h	*a*	*b*	*c*	PD (*a*+*b*)
			g 100^{-1}DM						
Pasture + shrubs	25	34	49	60	63^{a}	11.7	52.8	0.065	65^{a}
Pasture + shrubs + arboreals	33	42	57	67	70^{b}	9.8	61.7	0.082	72^{b}
Pasture + shrubs + arboreals + timber trees	35	45	60	69	71^{b}	9.5	64.1	0.089	74^{b}
p value Treatment	0.087	0.099	0.123	0.071	0.031	0.9185	0.0725	0.2115	0.0238
p value Treat*Season	0.061	0.067	0.081	0.072	0.079	0.2302	0.0176	0.1042	0.0097

Table 6.2. Variation in edible forage dry matter degradation characteristics of *Leucaena leucocephala*, harvested at the middle of the wet (August) and dry (February) seasons, and incubated for 8-72 hours in the rumen. Means for each variable within the same row with different subscript letters are statistically different at $p<0.05$.

Parameters of the fitted curve	Wet season	Dry season	p value
a	0.93^{a}	20^{b}	0.0023
b	65^{a}	54^{b}	0.0125
c (% h^{-1})	0.098^{a}	0.059^{b}	0.0233
PD (g 100^{-1} DM)	66^{a}	74^{b}	0.0113

Values of the constants in the equation $p = a+b\ (1-e^{-ct})$, where a = is the zero time intercept of the fitted curve (rapidly soluble fraction), b = insoluble but fermentable fraction in time t, c = the fractional-degradability rate constant at which the fraction described by b will be degraded per hour and PD = potential degradability.

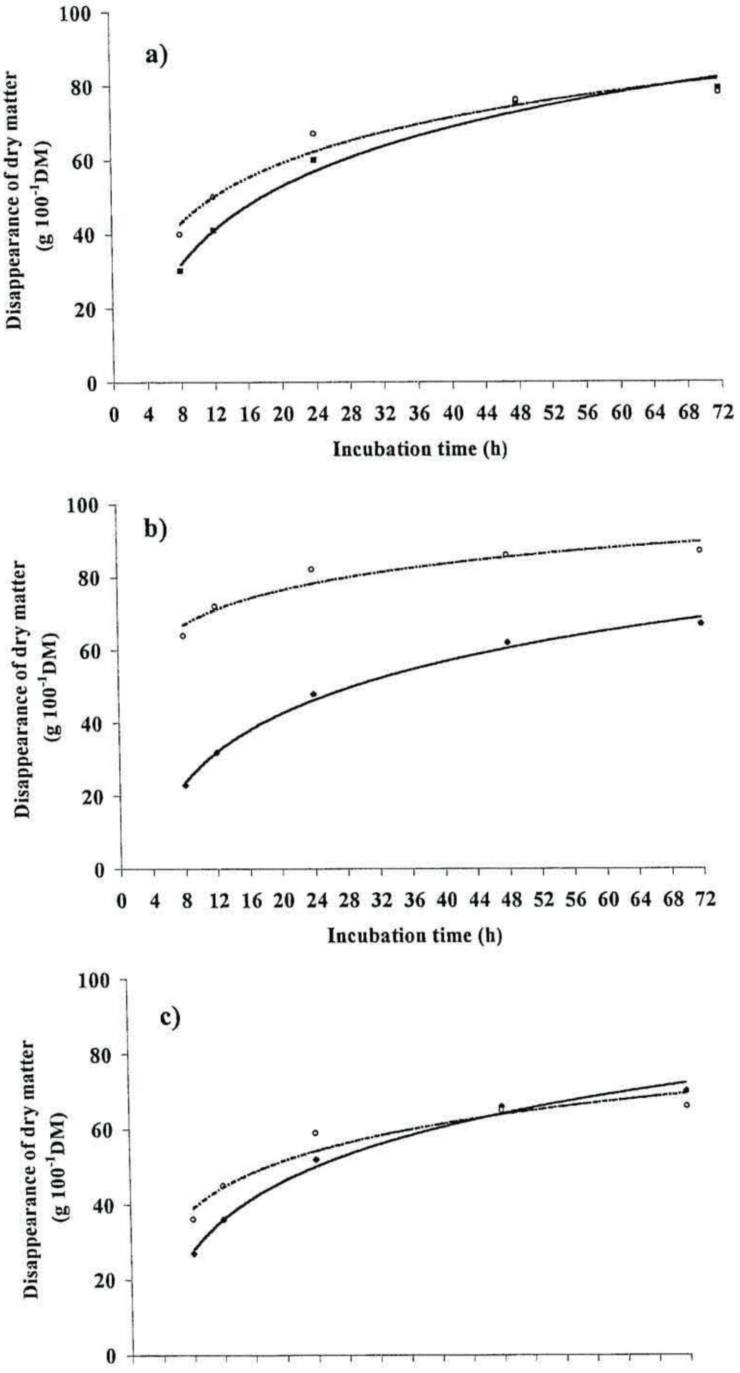


Figure 6.7. Dry matter losses during nylon bag degradability in the rumen for edible material of three shrub species a) *Crescentia cujete*, b) *Gliricidia sepium* and c) *Leucaena leucocephala*, harvested and evaluated at the middle of the wet season (August), broken line and dry season (February), solid line, in multistrata silvopastoral systems experiment with different levels of structural complexity.

6.3.3.2 Effects of treatment and season on arboreal species *(Albizia saman, Cassia grandis* and *Guazuma ulmifolia*)

None of the parameters of degradability of *A. saman* differed according to treatment. Potential degradability was significantly (P=0.0034) lower in the wet season than in the dry season (Figure 6.8), while the lag phase was significantly (P=0.024) shorter in the wet season (1.7 hours) than in the dry season (4.4 hours).

Except for the seasonal variation in the disappearance of the dry matter after 48 and 72 hours incubation in the rumen, there was no variation in any degradability parameters of *C. grandis* dry matter according to treatment. After 48 hours degradability of *C. grandis* was in the order of 52 g 100 g^{-1} DM and 58 g 100 g^{-1} DM for the wet and dry season respectively (P=0.0420). At 72 hours, degradability varied from 57 g 100 g^{-1} DM in the wet season to 63 g 100 g^{-1} DM in the dry season (P=0.0123).

Only season showed a significant (P=0.0171) effect on potential degradability amongst degradability components of *G. ulmifolia*. Potential degradability was higher in the dry season than in the wet season (Figure 6.8).

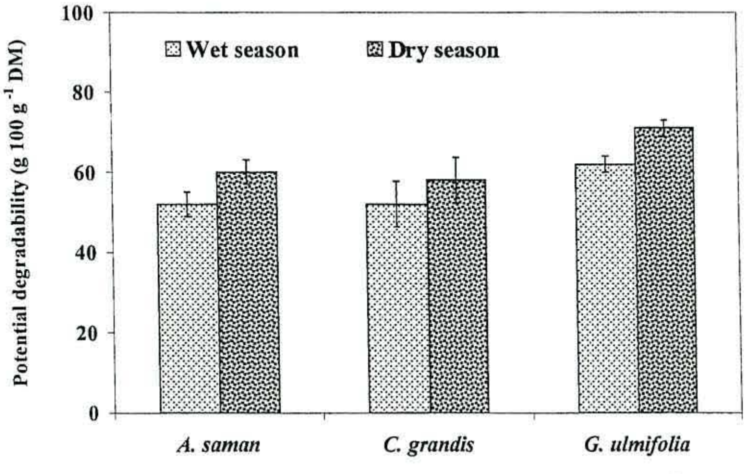


Figure 6.8. Potential degradability (*a*+*b*) of edible parts of three arboreal species harvested in the middle of the wet (August) and dry (February) seasons, in multistrata silvopastoral systems experiment with different levels of diversity and structural complexity. Bars indicate standard errors.

6.3.3.3 Effects of treatment and season on grasses and herbaceous legumes (*Dichanthium aristatum*, *Brachiaria mutica*, *Centrosema pubescens*, *Desmodium uncinatum*, *Rhynchonsia minima* and *Vigna sp).*

Potential degradability of *D. aristatum* was significantly higher in the more complex agroforestry treatments 4 and 5 (P=0.0096) (Table 6.3). A longer lag phase was associated with pasture only and arboreal species (treatment 3) (P=0.0389). The lag phase varied from 2.5 to 3.6 hours in treatments 5, 4 and 2 and from 6.1 to 4.9 hours in treatments 3 and 1. The differences in lag phase between treatment 3 and treatments 2, 4 and 5 were significantly different (P=0.0453, 0.0149 and 0.0069 respectively).

Table 6.3 Mean values of the effects of treatments on degradation of dry matter of *Dichanthium aristatum* in nylon bags incubated for 8-72 hours in multistrata silvopastoral systems experiment with different levels of structural complexity at Turipaná, Córdoba, Colombia. Means within the same column with different subscript letters are statistically different at p<0.05.

Treatments	8 h	12 h	24 h	48 h	72 h	*A*	*b*	*c*	PD (*a*+*b*)
	g 100^{-1}DM								
Pasture	24	31	45	56	59	-10.5	72	0.06	61^a
Pasture + shrubs	22	30	44	56	60	0.21	65	0.05	65^a
Pasture + arboreal	27	36	50	60	63	-14.2	80	0.07	65^a
Pasture + shrub + Arboreal	26	35	51	63	67	-1.2	71	0.06	70^b
Pasture + shrubs + arboreal + timber trees	26	35	51	65	70	2.3	70	0.05	72^b
p value	0.771	0.737	0.619	0.348	0.154	0.624	0.660	0.819	0.009

Values of the constants in the equation $p = a+b\,(1-e^{-ct})$, where a = is the zero time intercept of the fitted curve (rapidly soluble fraction), b = insoluble but fermentable fraction in time t, c = the fractional-degradability rate constant at which the fraction described by b will be degraded per hour and *PD* = potential degradability.

Potential degradability of *Rhynchosia minima* was significantly lower associated with pasture and shrub species and with pasture, shrub and arboreal species (treatments 2 and 4). The differences were significantly different between *R. minima* associated with only pasture, and with pasture and arboreal species (Table 6.4).

Table 6.4 Mean values of the effects of treatments on degradation of dry matter of *Rhynchosia minima* in nylon bags incubated for 8-72 hours in multistrata silvopastoral systems with different levels of structural complexity at Turipaná, Córdoba, Colombia. Means within the same column with different subscript letters are statistically different at $p<0.05$.

Treatments	8 h	12 h	24 h	48 h	72 h	*a*	*b*	*c*	PD (*a*+*b*)
			g 100^{-1}DM						
Pasture	27	36	51	62	66	-1.8	67	0.07	69^{a}
Pasture + shrubs	23	30	43	52	55	-0.44	56	0.07	56^{b}
Pasture + arboreal	28	28	52	63	65	2.11	65	0.07	67^{a}
Pasture + shrub + Arboreal	25	33	45	54	56	3.6	54	0.07	57^{b}
Pasture + shrubs + arboreal + timber trees	26	34	49	59	61	6.2	57	0.07	64^{a}
p value	0.819	0.745	0.454	0.085	0.026	0.829	0.401	0.980	0.023

Values of the constants in the equation $p = a+b\,(1-e^{-ct})$, where a = is the zero time intercept of the fitted curve (rapidly soluble fraction), b = insoluble but fermentable fraction in time t, c = the fractional-degradability rate constant at which the fraction described by b will be degraded per hour and *PD* = potential degradability.

Amongst the herbaceous vegetation, season had significant effects on potential degradability only for grass species. Potential degradability was significantly higher in the wet season than in the dry season for *Dichanthium aristatum* (P=0.0001) and *Brachiaria mutica* (P=0.0223). The seasonal variation in potential degradability for *D. aristatum* was more marked than in *B. mutica*. Mean values of potential degradability for *D. aristatum* were in the order of 76 g 100 g^{-1} DM in the wet season and 57 g 100 g^{-1} DM in the dry season, while the corresponding values for *B. mutica* were 79 g 100 g^{-1} DM in the wet season and 69 g 100 g^{-1} DM.

As shown in Figure 6.9a, disappearance of dry matter of *Dichanthium aristatum* revealed large differences between seasons at all incubation times. Approximately 60% of dry matter was fermentable in the first 24 hours in the wet season but only 30% in the dry season. *Brachiaria mutica* (Figure 6.9b) did not differ significantly at the two first incubation times, but subsequently losses of dry matter in the rumen were significantly higher in the wet season. *B. mutica* was more highly degradable in the dry season than *D. aristatum*.

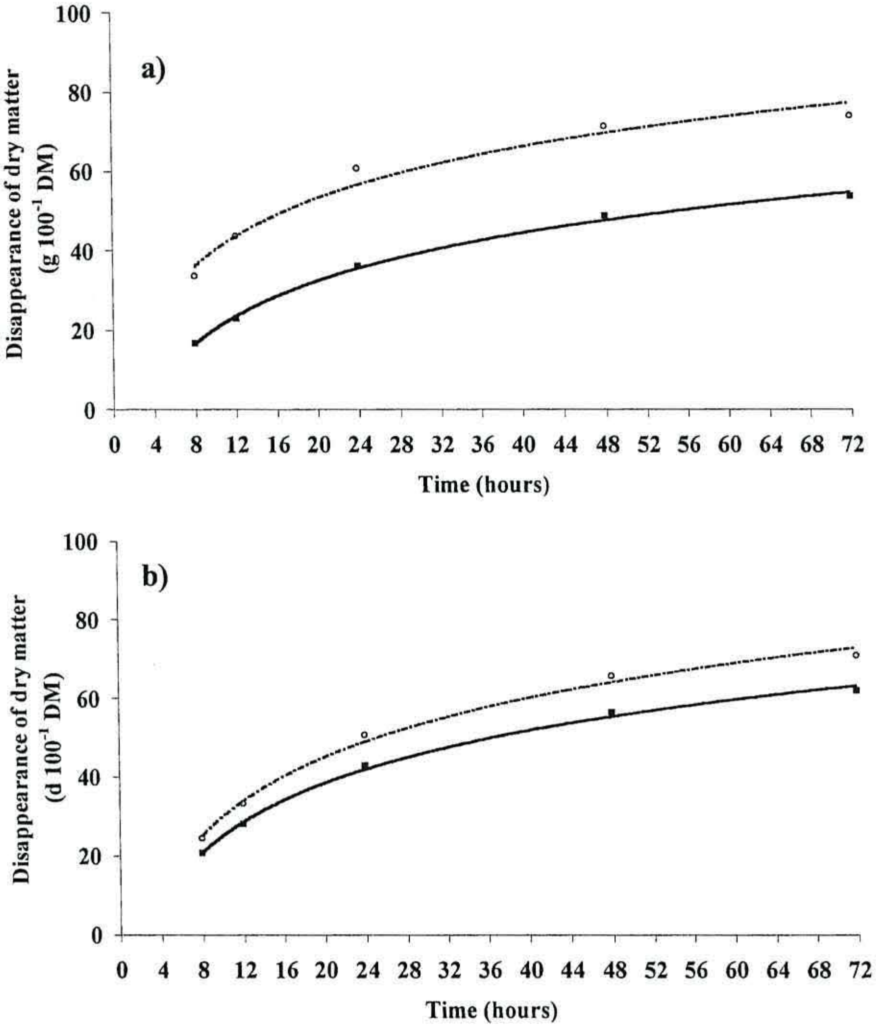
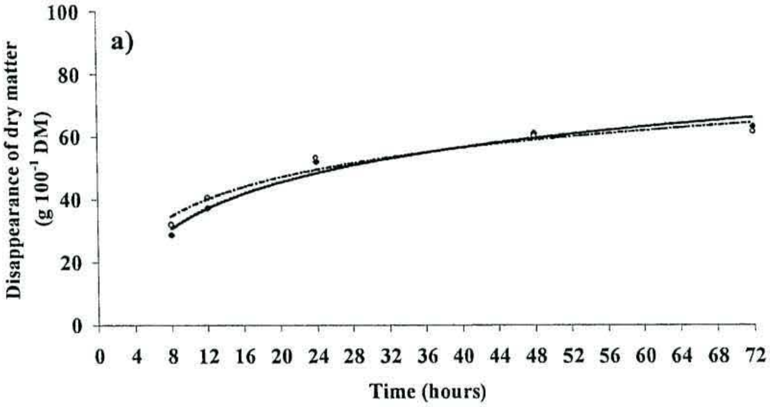


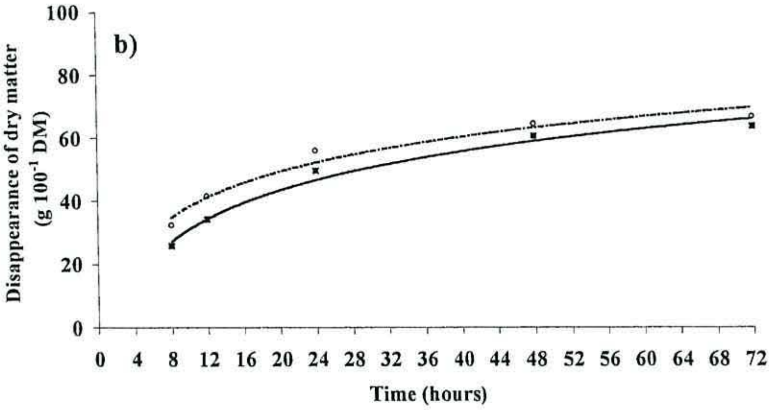
Figure 6.9. Dry matter losses during nylon bag degradability in the rumen for edible material of two grass species a) *Dichanthium aristatum* and b) *Brachiaria mutica,* harvested and evaluated in the middle of the wet (August), broken line and dry (February), solid line in biodiverse multistrata silvopastoral systems experiment with different levels of structural complexity.

No differences were found between seasons for *Centrosema pubescens* (Figure 6.10a), *Desmodium uncinatum* (Figure 6.10b) and *Rhynchosis minima* (Figure 6.10c) but significant effects between season were observed in *Teramnus uncinatus* from 8 to 48 hours, and in *Vigna sp* from 8 to 24 hours (Figures 6.10d and 6.10e respectively).

Vigna sp also degraded more rapidly than the other three herbaceous legumes. More than 60% of dry matter disappeared within the first 24 hours.

The correlation analyses between potential degradability, tannin content and nitrogen level of shrub, arboreal and herbaceous species did not suggest any relationship between those variables.





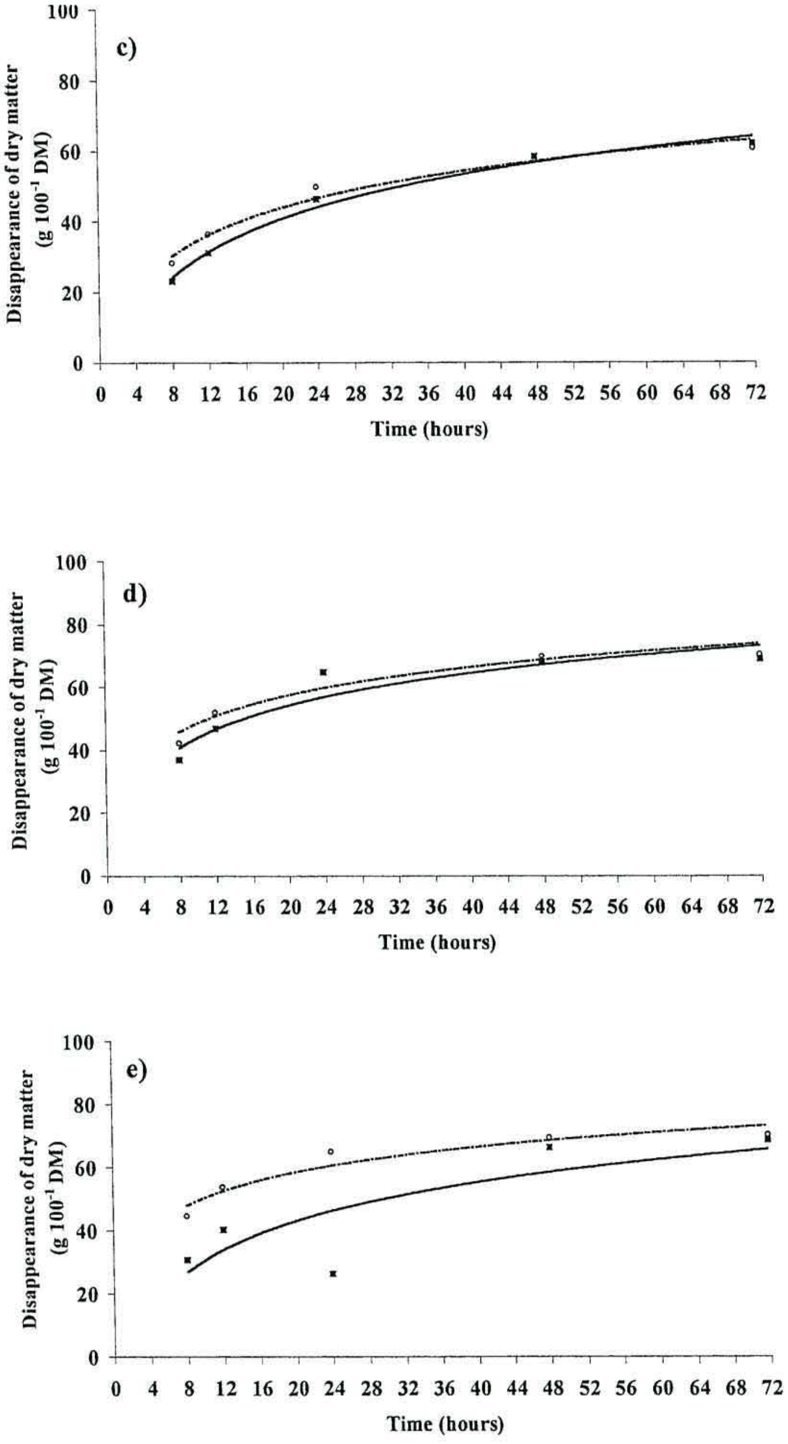


Figure 6.10. Dry matter losses during nylon bag degradability in the rumen of edible material of five herbaceous legumes, harvested and evaluated in the middle of the wet (August), broken line and dry season (February), solid line, in multistrata silvopastoral systems experiment with different levels of structural complexity: a) *Centrosema pubescens*, b) *Desmodium uncinatum*, c) *Rhynchosia minima*, d) *Teramnus uncinatus* and d) *Vigna sp.*

6.3.4 Rumen ammonia nitrogen

Treatment and season had a significant effect (P=0.0001) on rumen ammonia nitrogen concentration. Ammonia concentration was much lower in the dry season (12 mg l^{-1}) than in the wet season (38 mg l^{-1}). Rumen ammonia concentration for the open grassland control was lower than treatments 2 (P=0.0226), 4 (P=0.0003) and 5 (P=0.0001). In the wet season ammonia concentration in the control treatment was 29 and 35% lower than in treatments 4 and 5 respectively (Figure 6.11a) whereas in the dry season approximately 50% less ammonia was produced in the open grassland in relation to treatments 4 and 5 (Figure 6.11b). Figure 6.12 shows that in both wet and dry seasons ammonia concentrations in the open grassland treatment were much lower throughout the sampling time than in the more complex agroforestry treatments 4 and 5.

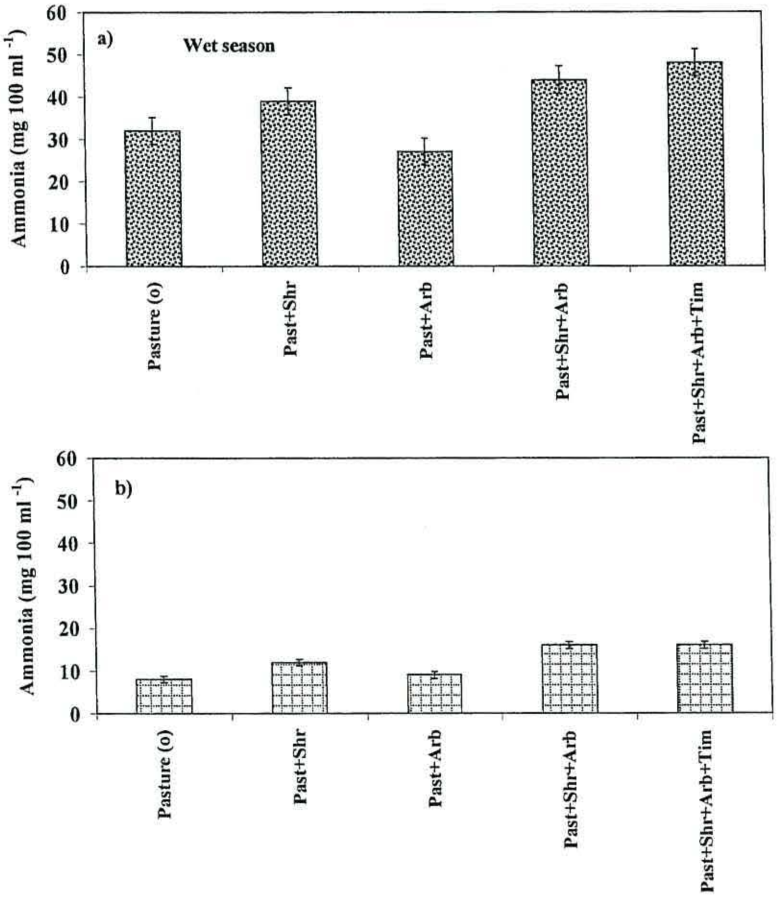


Figure 6.11. Mean ammonia concentration a) in the middle of the wet (August) and b) dry (February) seasons, in multistrata silvopastoral systems experiment with different levels of diversity and structural complexity. Bars indicate standard errors.

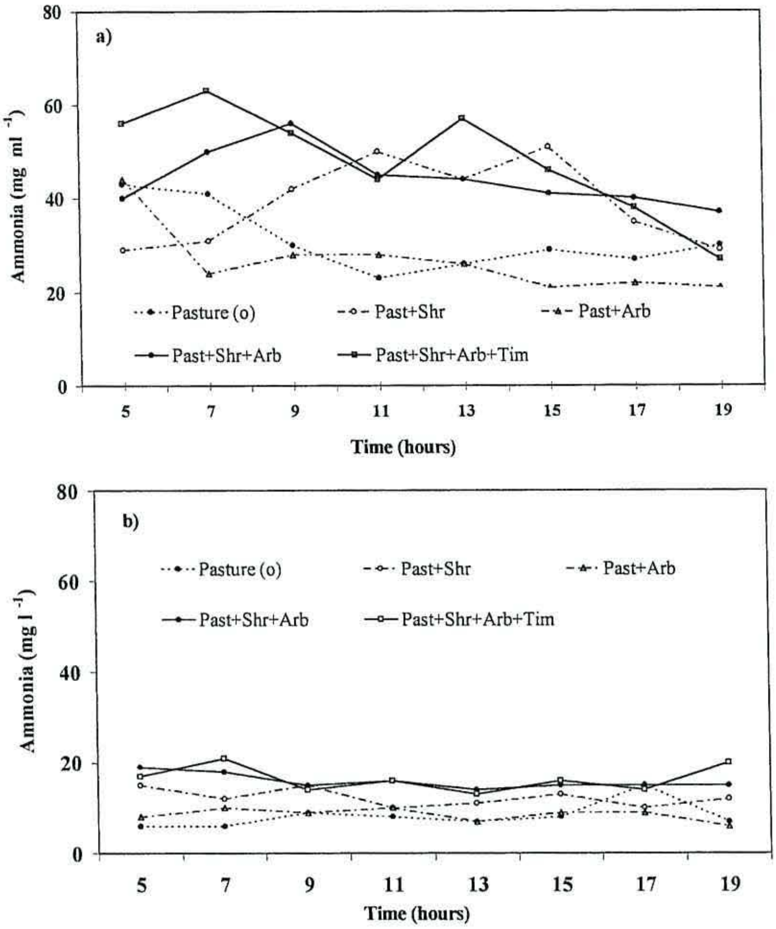


Figure 6.12. Mean of ammonia-nitrogen concentration in multistrata silvopastoral systems experiment with different levels of diversity and structural complexity in the wet (a) and dry (b) season.

6.3.5 Feed intake

6.3.5.1 Herbaceous and browse species - *n*-alkane concentrations

There were marked differences in the levels of alkane concentration between the individual species in this study (Table 6.5). The most abundant alkane within the herbaceous vegetation was C_{33}, except for *Dichanthium aristatum* and *Desmodium uncinatum*, which had a predominance of hentriacontane (C_{31}). Amongst the shrub species, the results showed a clear dominance of C_{33} and C_{31} for *Crescentia cujete* and there was a marked difference between the concentration of these alkanes in *C. cujete* compared with *Gliricidia sepium* and *Leucaena leucocephala*. *G. sepium* had a substantial amount of nonacosane (C_{29}). By contrast, the alkane concentrations in *L. leucocephala* were generally low, with highest concentration in this species of C_{29}.

Table 6.5. Concentrations of *n*-alkane in the cuticular wax of tropical grasses, herbaceous legumes and shrub species

Species	Mg kg^{-1} DM									
	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{33}	C_{35}
Grasses										
Dichanthium ristatum	4	19	9	61	12	52	9	49	31	6
Brachiaria mutica	3	7	4	13	7	25	7	79	112	28
Herbaceous legumes										
Centrosema pubescens	3	6	5	10	7	45	7	60	105	10
Desmodium uncinatum	2	4	3	9	7	33	7	85	52	3
Rhynchosia minina	2	5	3	5	3	11	3	63	109	6
Teramnus uncinatus	3	5	5	6	14	19	8	33	49	4
Vigna sp	2	4	3	10	5	21	7	90	185	8
Shrub species										
Crescentia cujete	2	3	3	4	4	10	12	108	145	49
Gliricidia sepium	3	5	8	39	17	144	7	36	19	10
Leucaena leucocphala	2	5	5	13	19	39	11	22	11	3

6.3.5.2 Diet composition and feed intake

Mean feed intake for the five cows used in this study was 13 kg DM day^{-1}. Figure 6.13 shows the proportion of each dietary component for the daily intake of each cow. Figure 6.14 shows the mean dietary proportions of herbage (grasses and herbaceous legumes) and shrub fodder; the dietary proportions of each species contributing to the shrub fodder component are also shown.

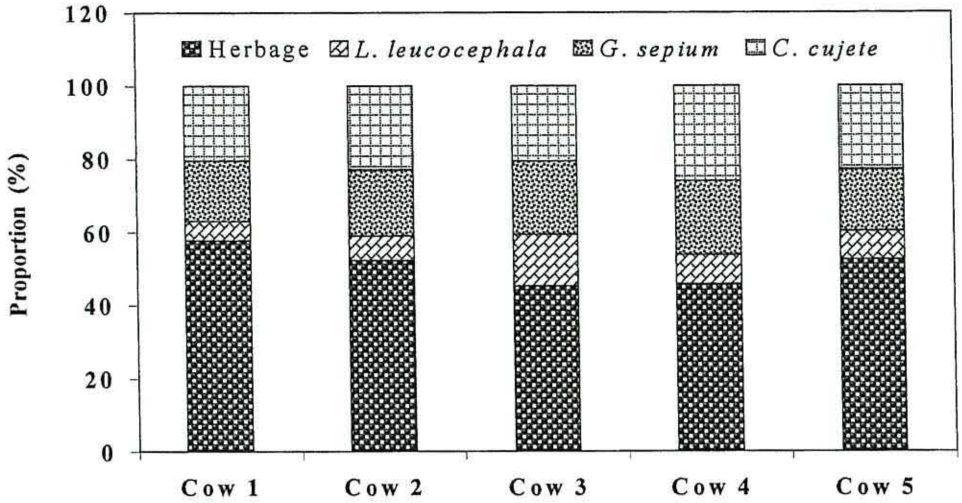


Figure 6.13. Proportion of each component of the daily diet eaten by milking cows grazing biodiverse silvopastoral systems comprising three shrub species and pasture.

It is clear from Figure 6.14 that about half of the diet was provided by shrub fodder, and *Crescentia cujete* appeared to be the shrub species contributing most to the diet, followed by *Gliricidia sepium.*

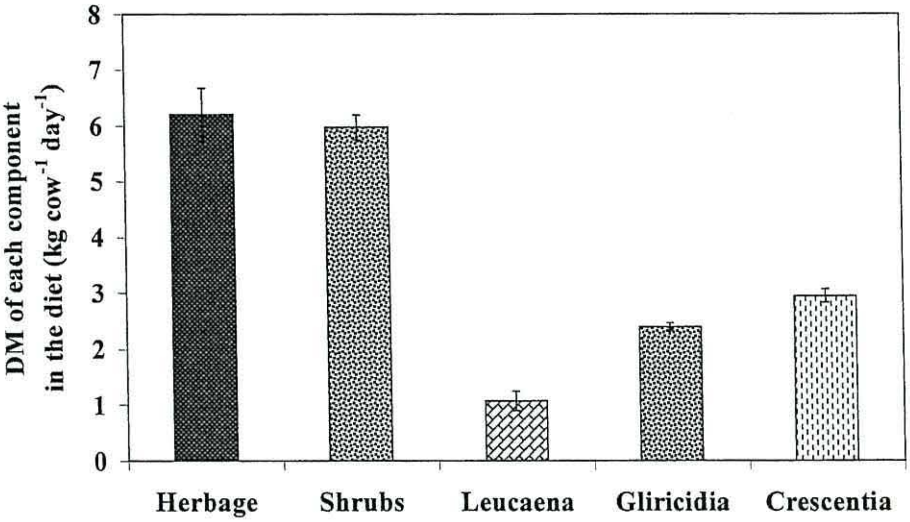


Figure 6.14. Mean daily intake estimates of the proportions of the herbage and shrub species in the diet of milking cows grazing diverse silvopastoral systems comprising three shrub species and pasture. Dietary proportions of the three shrub species comprising the shrub fraction are also shown.

6.4 DISCUSSION

6.4.1 Nitrogen content (N)

Treatment had no detectable effect on nitrogen content of the edible fraction of herbaceous, shrub, or arboreal species. As the trees may be considered young, it is possible that the effects of trees on feed quality of herbaceous vegetation may not occur until some years after establishment. Despite the lack of statistical differences, some differences in nitrogen content between the open control and the agroforestry treatments, suggest that the quality of the grass species might be improved by the presence of trees. Nitrogen content for instance in *Dichanthium aristatum* was 8.3% and 16.6% higher associated with arboreal species (treatment 3) and shrub and arboreal species (treatment 4) than the open grassland, while *Brachiaria mutica* nitrogen content was 5.8% higher associated with shrub species (treatment 2) and treatments 3 and 4 than the open grassland (see appendix 6.1). Quality changes have been associated with higher concentrations of nitrogen and potassium in forage growing under trees than in open grasslands (Wilson et al., 1990). The study of Wilson et al. (1990), which compared yield, and composition of *Paspalum notatum* under shade of *Eucalyptus grandis* in Queensland, Australia, showed an increase of 67% in nitrogen content under the trees than in open grasslands. In North Queensland, the effects of trees on pasture quality were investigated by monitoring the nitrogen concentrations and dry matter digestibility of a perennial grass (*Chrysopogon fallax*). Pasture quality tended to be higher under trees. Overall nitrogen of *C. fallax* leaves at all seven sampling times over 16 months was higher ($p<0.05$) under the canopy zone than outside (Jackson and Ash, 1988). It was suggested that the higher concentrations of nitrogen and other micronutrients in the grass were likely to reflect higher nutrient concentrations in the soil solution. It appears that under tree crowns there may be an additional input to soil nitrogen from accumulated leaf drop, which is likely to be more important under leguminous trees (Lowry et al., 1988) than under species with leaf litter of low nitrogen content (Wilson et al., 1990).

Nitrogen content varied with the season. Browse species such as *Gliricidia sepium* had higher nitrogen content in the wet season compared with the dry season, while Albizia *saman*, *Cassia grandis* and *Guazuma ulmifolia* were not affected by seasonal variation in climate, maintaining their high nitrogen content in the dry season. In comparison with shrub and arboreal species, grass species in both the wet and dry season were much lower in nitrogen content and between seasons, nitrogen content was generally lower in the dry season. The results of this research on fodder quality of shrub and arboreal browse species indicate that their nutritional characteristics, in terms of N content, are superior in both the wet and dry seasons to those of herbaceous species commonly used for fodder. Similar results have been found by Chadhokar (1978), Johg Ho Ahn et al. (1989), Aletor and Omodora (1994), Smith et al.(1995), Perera (1995), Larby et al. (1996a,b), Paterson et al. (1998), Mpairwe et al.(1998).

The decline in grass quality in the dry season as growth progressed is caused by the translocation of soluble carbohydrates from stem and leaves to the inflorescence, and increased content of lignified cell walls and a decrease in the ratio of leaf to stem, which occur as grasses flower and mature (Norton, 1981). Additionally climatic fluctuations have been associated with variations in yield and forage quality of grass species (Henderson and Robinson, 1982a). Cooper and Tainton (1968) stated that growth rate of most tropical grasses is influenced by temperature and light intensity. Conditions enhancing growth rates have frequently resulted in reduced forage quality (Henderson and Robinson, 1982b). Higher proportions of stem, fibre concentrations and lower carbohydrate concentrations often result from high temperatures during growth periods (Wilson and Ford, 1973). The inability of tropical grasses to maintain a sustainable level of animal production has generally been related to their lower nitrogen content (Mannetje, 1982; Minson, 1982).

The nitrogen content of shrub and arboreal species were sufficiently high to warrant consideration of their use as a source in producing protein to supplement poor quality pasture and fibrous crop residues (where they are available).

6.4.2 Tannin contents

Tannin levels of herbaceous vegetation ranged from 18 to 30 g kg^{-1} DM. Tannin content was influenced by season, with lower values in the dry season. In the shrub species in addition to the species effect, there was a significant interaction between season and species, with much lower tannin levels in *Leucaena leucocephala* in the dry season. This may be attributed to possible changes in leaf structure that could have occurred with the progress of the dry season. Although no corresponding results to confirm this were found in the literature reviewed, there is evidence that farmers improve *G. sepium* palatability by drying its leaves in the sun (Nitis, 1986). Oven drying of *Acacia aneura*, *Acacia angustissima*, *Acacia chinensis* and *Calliandra calothrysus* caused a reduction in 'active' tannins and this was reflected in an overall 35% improvement in rumen nitrogen digestibility (Anh et al., 1989). Values of *Gliricidia sepium* and *L. leucocephala* are in agreement with those reported by D'Mello (1992). No corresponding values were found for *Crescentia cujete*.

Amongst the arboreal species, *Cassia grandis* had the highest tannin levels and there was no evidence of a change in tannin content with season. With the exception of *C. grandis*, none of the species evaluated in terms of condensed tannins in this study reached levels higher than 5%. No evidence was found in the literature about which levels may be considered as high, moderate or low, and when such levels might reduce intake or result in diminution of the digestive process and consequently have detrimental effects on animal performance. Donnelly and Anthony (1973) suggested that levels of 3 g kg^{-1}DM were low and 8 g kg^{-1}DM high in leaves of *Lespedeza juncea*. Barahona et al. (1997) found in two tropical legumes, *Desmodium ovalifolium* and *Flemingia macrophyla*, levels of condensed tannins around 194 and 349 g kg^{-1}DM respectively; these were assumed to be high tannin concentrations. Given that the species evaluated in this research were lower than 50 g kg^{-1}DM, (except for *C. grandis*, which had 137 g kg^{-1} DM), and the lack of correlation with degradability, it may be assumed that the tannin levels reported in this study were low and they might be in accordance with beneficial rather than detrimental effects on animal production. In this regard, Mangan (1988) indicated that tannins in low to moderate concentrations prevent bloating and increase the flow of non-ammonia nitrogen and essential amino acids from the rumen. Several studies have shown the mechanisms by which tannins may increase the efficiency of protein utilization by ruminants. According to Mangan (1988) tannins may complex protein at the pH of the rumen and protect it from microbial enzymes. Driedger and Hatfield (1972) and Reed (1995) suggest that tannins may increase the efficiency of urea recycled to the rumen. Therefore, tannins may enhance microbial yield (Reed et al., 1990).

6.4.3 Dry matter degradability

As expected species responded differently in terms of dry matter degradability in relation to the different environments and seasonal variation in climate. Overall dry matter degradability varied from very high (70-80 g 100 g^{-1} DM) in species such as *Gliricidia sepium*, *Crescentia cujete*, *Vigna sp.*, *Brachiaria mutica* and *Leucaena leucocephala*; moderate (above 60 g 100 g^{-1} DM) in *Desmodium uncinatum*, *Teramnus uncinatum*, *Guazuma ulmifolia*, *Cassia grandis* and *Rhynchosis minima* to low (less than 60 g 100 g^{-1} DM) in *Albizia saman*. Responses to seasonal variation occurred in *D. aristatum*, *B. mutica*, *G. sepium* and *G. ulmifolia*. While the two grasses and the shrub species had lower potential degradability in the dry season, *G. ulmifolia*, one of the arboreal species, showed the reverse response with higher potential degradability in the dry season.

The most interesting result of the degradability evaluation in a multistrata context was the observation of a considerable improvement in potential degradability of *D. aristatum* associated with the more complex multistrata treatments, 4 and 5. Potential degradability of *D. aristatum* was 15% higher associated with shrub and arboreal species (treatment 4) and 18% associated with shrub, arboreal and timber species (treatment 5) than in the control pasture only treatment. Tropical C_4 grasses are characterized by producing forage of poor quality (Minson and McLeod, 1970), and it has been suggested that the high temperatures in tropical regions may be a cause of this (Wilson et al., 1976). High temperatures generally increase the concentration of fibre in forages and this effect occurs with both tropical and temperate grasses (Minson, 1990). Direct experimentation has confirmed that high temperatures normally decrease the dry matter digestibility of growing herbage by increasing rates of plant development and consequent synthesis of stem material (Allinson, 1971). It has been suggested that a high rate of transpiration is a factor contributing to the low dry matter digestibility of forages growing at high temperature (Minson and McLeod, 1970). This could be due to the development of a larger vascular system to convey the greater quantities of water passing through the plant, or to wilting that occurs whenever soil is unable to supply water at sufficient rates to meet the potential evapotranspiration (Minson, 1990). One of the main factors controlling digestibility of some tropical grasses is the proportion of hemicellulose and cellulose present in the plant and the extent to which they are lignified (Minson, 1971).

Studies in controlled-temperature rooms showed that dry matter digestibility of grasses declined by a mean rate of 0.006 for each °C rise in temperature over the normal growth range (Minson and McLeod, 1970). In subsequent work, Wilson and Minson (1983), showed that high growth temperatures decreased the dry matter digestibility of stem and stubble of *Macroptilium atropurpureum* by 0.0026 and 0.0056 units per 1°C respectively. Their work showed that in contrast to the stem and stubble fractions, leaves showed a reverse result to temperature increasing dry matter digestibility by 0.0022 units per 1°C. When grasses are subjected to soil water stress and high evaporative demand, effects on nutritive quality have also been reported. Leaf *in-vitro* digestibility of *Panicum coloratum* organic matter decreased from 60% at 28% soil moisture to 43% at 7% soil moisture (Pitmal, et al., 1981).

It is possible that in this study leaves and stems of *D. aristatum* were benefited by a local microclimate created by the intermediate and high numbers of strata of treatments 4 and 5, where reduced temperatures, increased soil moisture and reduced evaporative demands might have enhanced the production of more succulent leaves, and resulted in higher potential degradability of the dry matter of *D. aristatum*. Plants grown in the shade in the study reported by Gordon et al. (1962) were more succulent, resulting in a lower dry matter percentage. A possible explanation for this may be given by the fact that shade modifies the structure of the leaf. In a study by Ludlow and Wilson (1987), shaded leaves of *Panicum maximum* and *Phaseolus atropurpureus* were thinner, and contained fewer, smaller and less densely packed cells, and had smaller specific leaf weight (leaf dry weight per unit leaf area) than unshaded leaves.

Contradictory results were observed from several studies reporting on effects of environment on dry matter digestibility as a result of increased shade or nutrients. The study of Henderson and Robinson (1982b) indicated that light levels did not influence in-vitro digestibility at low soil moisture levels, but at high soil moisture levels maximum in-vitro digestibility of coastal Bermuda grass sp. and common Bermuda grass sp. occurred at low photon flux density. A stronger response of increased dry matter digestibility for leaves than for stems of shaded grasses was reported by Samarakoon et al. (1990). In this study, dry matter digestibility of fully expanded leaves of *Stenotaphrum secundatum* and *Axonopux compressus* was increased by shade at low and high nitrogen levels, and the increase was larger at high nitrogen fertilization levels, suggesting that an increased nitrogen mineralization was enhanced by shade effects. Increased pasture quality in terms of in-vitro digestibility values of the dry matter have been found under intact woodland compared to cleared land (Jackson and Ash, 1998; Ash and McIvor, 1998). In this study, dry matter digestibility of *Chysopogon fallax* collected from outside-canopy and under-canopy were 50 and 56% respectively. In a controlled-environment experiment, plants of *Chrysopogon fallax* and *Heteropogon contortus* were grown in soil collected either from beneath canopies or from inter-canopy areas. Plants growing in under-canopy soil had higher leaf dry matter digestibility than plants in outside-canopy soil (Jackson and Ash, 2001). However, when the effects of simulated shade were evaluated, dry matter digestibility was unaffected by the level of shading used.

The increase in potential degradability of *Dichanthium aristatum* may not only be due to the ecological factors mentioned above, but also to more favourable conditions in the rumen which could have stimulated the growth activity and fibre-degrading microbial population (Ørskov, 1988). *Leucaena leucocephala*, consistent with the trend observed in *D. aristatum*, had higher potential degradability associated with treatments 4 and 5, and dry matter of *L. leucocephala* over all the incubation times was fermented faster in these treatments than in treatment 2. Since *L. leucocephala* also had the highest nitrogen content amongst species, there was possibly more nitrogen released in the rumen, which might have contributed to more favourable conditions in the rumen for plant cell-wall degrading microorganisms. It may not have been only *L. leucocephala* that contributed to more nitrogen release in the rumen, since other species growing in treatments 4 and 5 such as *Guazuma ulmifolia* may have contributed to improving the conditions of the rumen in comparison with less complex agroforestry systems and the grassland control. The better conditions in the rumen that may have enhanced microbial growth and consequently *D. aristatum* degradability are also supported by higher levels of ammonia concentration produced in the more complex agroforestry treatments 4 and 5 in comparison with those on the open grassland treatment. Supplementation of poor quality grass and roughage diets has been shown to increase digestibility and intake (Minson and Milford, 1967; Silva and Ørskov, 1988). The use of strong alkalis and ammonia has been widely advocated to improve the nutritive value of crop residues (Mosi and Butterworth, 1985; Silva and Ørskov, 1988). However, in farming systems in the tropics with low inputs, farmers are unlikely to buy supplementary feed to improve poor quality grass to enhance animal production (Preston and Leng, 1987). Therefore, a large number of shrub species are being used to improve the production of ruminants consuming tropical grasses. Dry matter digestibility of stargrass was higher when 20 and 30% of *G. sepium* leaves were added to the diet. The additional amount of *G. sepium* leaves resulted also in a higher ammonia concentration in the rumen (Alayon et al., 1998). Digestibility by Ethiopian Menz sheep fed a teff (*Eragrostis tef*) straw basal diet improved from 48 to 55% when sheep were supplemented with *L. leucocephala* (Bonsi et al., 1994). Ammonia levels in Ethiopian Menz sheep varied from 39 mg l^{-1} with only teff straw to 107, 130 and 143 mg l^{-1} with 175, 245 and 315 g day^{-1} of *Sesbania sesban* respectively (Bonsi et al., 1994). Levels of 117, 178, and 232 g day^{-1} of *L. leucocephala* supplementing a teff straw basal diet, increased ammonia levels from 21 (teff straw only) to 47, 70 and 83 mg l^{-1} respectively (Bonsi et al., 1995). In both cases, *L. leucocephala* and *S. sesban* supplementation promoted high levels of rumen ammonia that probably enhanced microbial growth and proliferation. Although the overall mean of ammonia concentration levels in the more complex agroforestry treatments 4 and 5 were lower than those reported by Bonsi et al. (1995) and those suggested by Satter and Slyter (1974) and Leng (1990) to optimise microbial growth, the results of this study clearly indicate that the addition of shrub and arboreal species such as *C. cujete*, *G. sepium*, *L. leucocephala* and *G. ulmifolia* can ensure to increase ammonia in the rumen to supply the majority of nitrogen required for microbial growth which is the first priority in optimising fermentative digestion of forage (Leng, 1990). This has a positive effect by enabling the microbes to increase the rate of digesta breakdown. As the rate of breakdown and passage of the digesta increases, feed intake is increased accordingly (van Soest, 1982), enhancing animal production.

As expected grass species had higher potential degradability in the wet season compared with the dry season, and disappearance of dry matter was also faster in that period. This may be explained by an increase in the concentration of cellulose, hemicellulose and lignin during the dry season. Dry matter digestibility of most forage is low in the middle of the dry season, and differences in digestibility could be caused by changes in temperature, water availability, or light (Minson, 1990). Potential degradability varied between *Gliricidia sepium* and *Guazuma ulmifolia*, with lower degradability in the dry season for *G. sepium* and higher for *G. ulmifolia*. The reasons for this are not known , and they should be studied further.

6.4.4 Feed intake

There are a number of studies, which have demonstrated large differences in alkane patterns between species (Dove, 1992; Dove and Mayes, 1991; Laredo *et al.*, 1991). Concentrations of C_{29}, C_{31} and C_{33}, similar to those found in this study for *Leucaena leucocephal*a were found by Laredo *et at.*, (1991). The results of this research agree with previous reports that the predominant alkanes of cuticular wax are C_{25}-C_{32} in chain length, with C_{29}, C_{31} and C_{33} present in the highest concentrations (Mayes *et al.*, 1986a; Dove, 1992; Dove *et al.*, 1996; Hameleers and Mayes, 1998).

The most remarkable result of the feed intake evaluation using the *n*-alkane technique was the finding that about half of the diet was provided by shrub fodder. The feed intake measurements were conducted during the dry season, when the mean dry matter of herbaceous vegetation at the site was 2.4 t ha^{-1} less than in the wet season (6.2 compared with 3.8 t ha^{-1} in the dry season) (see results of DM in Chapter 5). Therefore, the results of feed intake confirm that shrub species have enormous potential as a feed source for ruminants, on seasonally dry pasture when availability of herbaceous vegetation is low.

Mean feed intake for the five cows with mean body weight of 420 kg and milk yield of 5 l cow^{-1} day^{-1} used in this study was 13 kg DM day^{-1}. Hendricksen and Minson (1980) reported values of feed intake of 11.5 kg DM day^{-1} for cattle grazing a *Lablab purpurea* sward and Kibon and Holmes (1987) reported 15.1 kg DM day^{-1} for lactating cows grazing perennial ryegrass supplemented with a cereal-based concentrate or a sugar-beet pulp.

The estimates of intake obtained using the *n*-alkane method appear to be reasonable, considering the milk yields and animal liveweights. Thus the results of this study suggest that the *n*-alkane technique can be successfully used to estimate feed intake of the two major dietary components: herbaceous vegetation and shrub fodder. However, due to large differences in the overall concentrations of alkanes in different plant species, the contribution of some individual species in the diet may not be accurately estimated. The differences between *C. cujete* and *L. leucocephala* in their overall alkane concentrations (Table 1) could have affected the estimation of the proportion of *L. leucocephala* in the diet. Despite the fact that *L. leucocephala* intake may have been underestimated, the *n*-alkane method provides a basis for separating four components of a complex diet and estimation of the overall feed intake of large grazing ruminants. Other methods, such as ^{13}C and ^{12}C isotopes, only estimate the proportion of C_3 and C_4 plant species in the diet. These approaches do not allow the separation of mixtures to the level of individual plant species (Dove, 1992). Visual scoring of grazed and browsed species can provide information to estimate species contributing to diet but they give little indication of the proportions of each species in the diet. The use of visual scoring to establish which species are present in the diet, together with the *n*-alkane method to determine the proportions of those species with sufficiently high alkane content and other markers for species with low alkane content may be an appropriate means of determining dietary composition of complex vegetation.

6.4.5 Conclusions

Amongst other factors the dietary treatments were imposed to study the supply of nutritional components from the different mixtures of species. The treatments were also utilised to investigate some implications of the shrub and tree species and the structural complexity of the systems on the nutritional quality of herbaceous components. The statistical analysis did not show any significant effect of treatment on nitrogen and tannin contents in any of the species. However, the additional species (shrubs and trees) involved in the multistrata treatments may contribute to the diet with their higher nitrogen content in producing more protein, thus might improve the basal diet offered by the pasture species. In this study there is evidence that a grass such as *Dichanthium aristatum*, considered of poor quality and widely spread in the farming systems of the Caribbean region improved its degradability in relation to more complex treatments. It is possible, and therefore, that under these conditions, and with the mixed diets that result, there be changes in rumen conditions that could enhance the amounts of nitrogen being released in the rumen. Improvements in animal productivity could be achieved by small changes in rumen conditions, which make utilisation of the basal diet more efficient.

In this study tannin contents were low and the poor relationship between tannin content and rumen degradability suggested that the different mixtures of species might not have detrimental effects on rumen digestion.

Environmental factors such as increased soil moisture, reduced evaporation and evapotranspiration and reduced temperatures that may occur in the more complex multistrata treatments appear to be important factors which affect nutrition, and further research should be conducted to explore the ecological and nutritional interactions involved in this type of system in the tropics.

CHAPTER 7

ANIMAL PRODUCTION ON MULTISTRATA SILVOPASTORAL SYSTEMS

7.1 INTRODUCTION

The quantity and quality of forage in the tropics are often constraints on animal production. Low animal growth rate, infrequent pregnancies and low milk yield, associated with the overgrazing of natural or improved pasture, are common characteristics of animal production in tropical areas (Ørskov, 1993). In seasonally dry parts of the tropics, dry matter production of forage is generally low and nutritive value in terms of overall digestibility and the amount of digestible nutrients is often also low (Crowder and Chheda, 1982). Animal production also tends to follow the seasonal variability in quality and quantity of pastures, mainly because of pronounced effects of the low efficiency of utilization of "low quality" forage in dry periods (Leng, 1990). The efficiency with which absorbed nutrients are converted to ruminant products (live weight, milk or meat) is dependent on precisely meeting the animal's requirement for the individual nutrients required for a particular function (Preston and Leng, 1987). These, at times, are influenced by body conditions as affected by previous health and nutritional history (Leng, 1990), the demands for body temperature control (Blaxter, 1962) and the substrate oxidation for exercise or work. Graham et al. (1959) showed that the quantitative oxidation of individual nutrients (largely fat) depended on the degree of heat stress in the case of animals in the tropics.

It was reported previously that livestock production in the Caribbean region of Colombia (West of the Magdalena River) depends largely upon grazing of improved and/or unimproved pasture and, only in some areas, are diets supplemented with crop residues (Section 2.3.2). Milk production in the region largely comes from multipurpose animals and milk yield per cow is low, at around 800 l per cow per lactation (CORPOICA, 1996). This low production is probably largely a result of poor nutrition, particularly where pasture makes up a significant part of the diet. Therefore, diet supplementation appears to have a large potential to improve productivity of the farming systems of the region and, fodder trees might play a role in providing protein and energy to poor quality forages through availability of green leaf material and fruits, especially when herbaceous fodder is scarce and of low nutritive value. This chapter reports on research on the impacts of silvopastoral systems with different levels of species diversity and structural complexity on production of grazing cattle. The objective of the research presented in this chapter was to evaluate the effects of shrub and arboreal fodder species on milk production from seasonally dry pastures.

7.2 METHODOLOGY

7.2.1 Animals

In the wet season of 1999, thirty-six dual purpose cows (used for both milk and beef production) Holstein x Brahman crosses with a mean body weight of 407 kg (standard deviation = 45), parity number from 1 to 3 and number of days into their lactation varying from 50 to 200, were used to evaluate the effects on milk production over a 100 day period of four agroforestry treatments (as described in Chapter 4, Table 4.1, Figure 4.1) and an open grassland control. The cows were divided into three groups, and each group of 12 cows was allocated to one of the three replicate blocks (see Table 7.1). The cows were assigned to groups based on milk yield prior to the trial, parity and days in milk, so that each group of cows had similar characteristics. In any case, regression analyses have previously suggested that there is no relationship between milk yield and lactation period and parity number in these cows (Ossa et al., 1994, 1997).

In the dry season of 2000, 15 Holstein x Brahman cows with a mean body weight of 420 kg (standard deviation = 40) in from their first to fourth parity and varying from 50 to 190 days into their current lactation were used to measure milk yield over 100 days. Distribution of the cows in each of the three groups followed the same method as explained above for 1999.

7.2.2 Grazing and carrying capacity

Each group of cows was rotated every ten days through the five treatments (including the control) within each replicate (block). Before grazing started, in both wet and dry seasons, the rotation order was randomised (Table 7.1).

Table 7.1. Sequence indicating the rotation system in both wet and dry season.

Season		Sequence of rotation of cattle (by treatment number as referred in Chapter 4)				
Wet						
	Block 1	T 1	T 2	T 5	T 4	T 3
	Block 2	T 2	T 1	T 4	T 3	T 5
	Block 3	T 1	T 2	T 3	T 5	T 4
Dry						
	Block 1	T 1	T 2	T 4	T 5	T 3
	Block 2	T 4	T 3	T 5	T 1	T 2
	Block 3	T 2	T 5	T 1	T 3	T 4

Each group of cows grazed on each treatment for a 10 day period, then rotated to the next treatment. Therefore, each treatment plot was occupied for 10 days and 40 days were allowed for recovery of the herbaceous and tree biomass. Each group of cows rotated twice through each treatment plot.

In both wet and dry seasons dry matter availability was assessed before the cows entered and after they vacated each treatment plot as described previously in Section 5.2.1. Dry matter availability was used to adjust the carrying capacity of each plot. The "*put and take*" method was used to adjust the carrying capacity according to the following formula (Paladines and Lascano, 1983). The cows that were used to adjust carrying capacity came largely from the same herd as the core cows although there were also five fistulated heifers used for the study of fodder nutrition (Chapter 6). These buffer cows were kept on a separate plot of *Dichanthium aristatum* until needed in the experiment.

$$C = \frac{100dA}{f(g+r)}$$

C = Carrying capacity (kg live weight ha^{-1})

d = Dry matter availability (t ha^{-1})

A = Plot area (2 ha)

g = Grazing period (10 days)

r = Recovery period (40 days)

f = multiplier (kg DM per 100 kg LW^{-1}); 9 in the wet season and 3 in the dry season.

7.2.3 Milk production

Milk yield was recorded daily for the core cows and also for those cows used to adjust carrying capacity. Milking occurred every day at 6.00 a.m. using a milking machine (Alfamatic VP-76, installed in tandem and with capacity for 12 units). Prior to milking, cows were stimulated by their calves to "let down" their milk. After milking the cows were allowed to feed their calves for approximately 30 minutes then returned to their treatment plots. The cows having calves less than 4 months old returned with them to the paddocks and calves were separated from their mothers at around 2.30 p.m. until the next morning.

7.2.4 Analyses

7.2.4.1 Milk production per cow

Daily milk production per cow was analysed using the daily milk yield from each individual cow of each core group. From the 10 day grazing period, only the final three days data were included in the analysis, to avoid the carry-over residual effects of the previous treatment. As in each season different groups of cows were used, milk yield from each season was separately analysed.

7.2.4.2 Milk production per hectare

Analysis of milk production per hectare was also calculated on the basis of the last three out of 10 days data, including the milk yield of all cows grazing in those three days (core cows plus cows used to adjust the carrying capacity).

Daily milk per cow and milk production per hectare, were analysed using the following statistical model:

$$Y_{ij} = \mu + B_i + T_j + BT_{ij} + E_{ij}$$

Where:

Y_{ij} = milk yield per cow or per hectare (l cow^{-1} day^{-1} or l ha^{-1} day^{-1})

μ = mean

B_i = Block effect

T_j = treatment effect

BT_{ij} = Interaction between block and treatment

E_{ij} = Residual error

Data were analysed using a mixed procedure model in SAS (SAS Institute, 1992) and differences between treatments investigated using planned contrasts or the LSMEANS procedure.

7.3 RESULTS

7.3.1 Milk production per cow

Mean yield in the wet season was 4.8 l cow^{-1} day^{-1} (s.d. 0.99). There was no block or treatment effect on mean milk yield per cow in this season (June-September 1999). In the dry season there was a significant effect of block (P=0.0221) on daily milk yield per cow, with significantly higher milk yield in block 3 than in blocks 1 and 2 (P=0.0001).

A planned contrast showed that milk yield in the agroforestry treatments was significantly higher than in the control plots (P=0.025) (Figure 7.1).

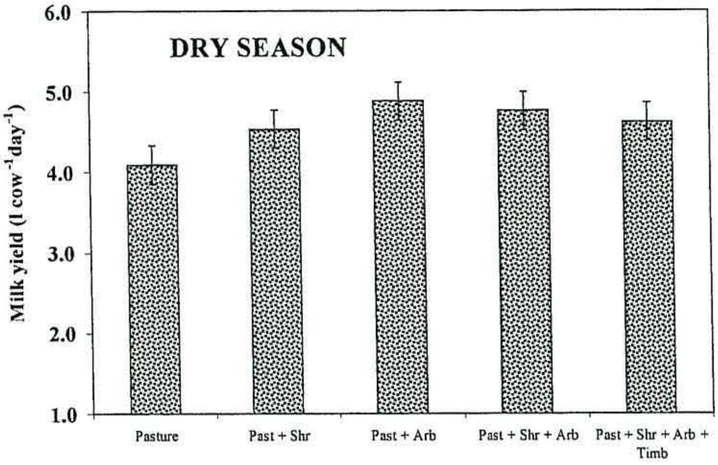


Figure 7.1. Mean daily milk per cow in the dry season, data correspond to measurements between January and April 2000 in silvopastoral systems experiment with different levels of shrub and tree diversity. Bars (I)indicate standard errors.

7.3.2 Total daily milk per hectare

In the wet season treatment had a significant effect on milk yield per hectare (P=0.010). Milk yield in the agroforestry treatments was higher than in the control plots (P=0.009) (Figure 7.2).

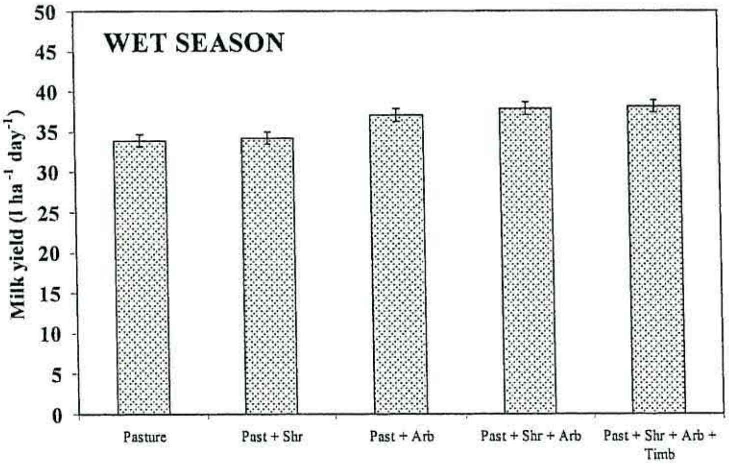


Figure 7.2. Mean daily milk yield ha^{-1} of dual purpose cows in the wet season (June to September 1999) in a silvopastoral systems experiment with different levels of shrub and tree diversity. Bars indicate standard errors.

In the dry season there were no significant effects of treatment on milk production when all three blocks were included in the analysis, although treatments with a high density of shrub and arboreal trees had consistently higher mean milk yield per ha than the control and treatment with the lowest density of trees (Figure 7.3). There was much higher variability associated with the dry season treatment means (compare standard errors in Figures 7.2 and 7.3) and this appeared to be associated with atypically wet conditions in block 3 that resulted in higher milk production in this block (Figure 7.4). There had been unusually high rainfall prior to the measurement period, and waterlogging was periodically observed in block 3, which was clearly poorly drained (as was confirmed by spot measurements of soil moisture). It was decided, therefore, that since block 3 may not be typical of dry season pastures in the region due to peculiar drainage, the data from blocks 1 and 2 should be analysed alone. In this further analysis, daily milk yield per hectare was higher in the agroforestry treatments than in the control (P=0.024; Figure 7.5), and in the high tree density plots (treatments 2, 4 and 5) than in the control and low tree density plots (P=0.020). Milk yield per ha was also positively correlated with shrub biomass recorded at the end of the previous wet season (Figure 7.6; P=0.003) and during the dry season (P=0.006).

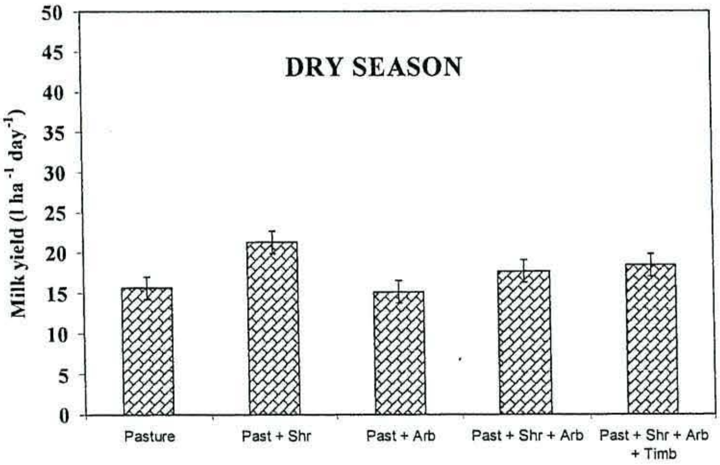


Figure 7.3. Mean milk yield ha^{-1} by treatment of dual purpose cows in the dry season (January-April 2000), in a silvopastoral systems experiment with different levels of shrub and tree diversity. Bars indicate standard errors.

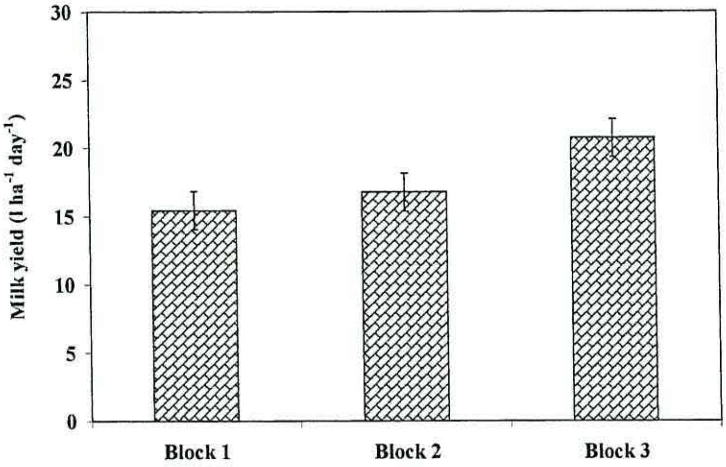


Figure 7.4. Mean milk yield ha^{-1} by block recorded between January-May (dry season 2000) in a multistrata silvopastoral systems experiment with different levels of tree and shrub diversity. Bars indicate standard errors.

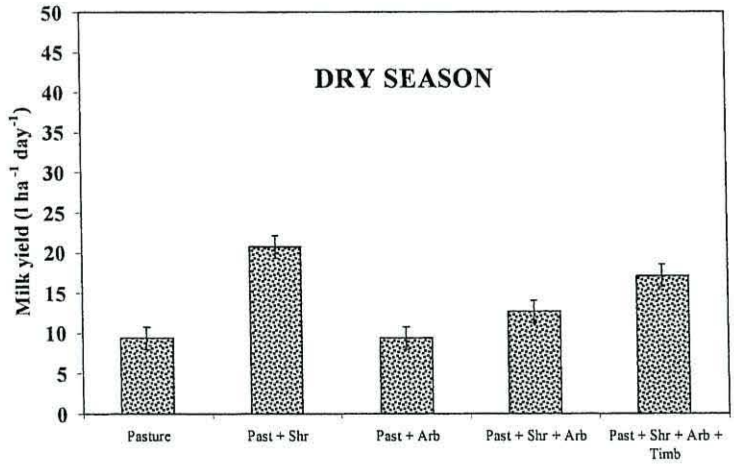


Figure 7.5. Mean milk yield of dual purpose cows in the dry season (January-April 2000), in a silvopastoral systems experiment with different levels of shrub and tree diversity using data from blocks 1 and 2 only. Bars indicate standard errors.

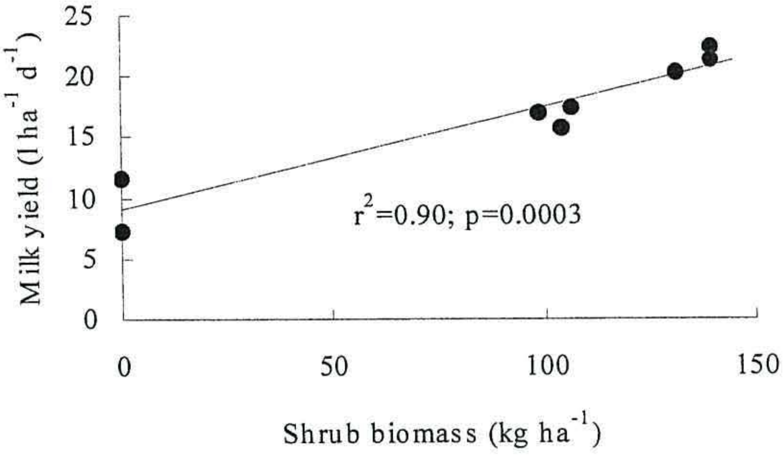


Figure 7.6. Correlation of dry season milk yield per hectare with shrub biomass in blocks 1 and 2 of a multistrata silvopastoral systems experiment. y = a + bx, a is intercept, b is slope of line.

7.4 DISCUSSION

7.4.1 Milk yield per cow

Since the objective of this research was to investigate the effects of the presence of trees under dry conditions, the discussion is mainly focused on the results obtained in the dry season. The results indicated that milk yield was higher in the agroforestry treatments compared with the open grassland control plots. It is clear from the results of pasture production presented in Chapter 5 that dry matter of herbaceous vegetation was much lower in the dry season than the wet season (see Chapter 5, Figure 5.2). Shrubs and trees undoubtedly provided additional dry season fodder leading to higher milk production per cow, this may also indicate that much of the dry matter eaten throughout the dry season was supplied by the shrub species and also perhaps by some of the arboreal species, especially *Guazuma ulmifolia*, which appeared from observations of the researcher to be extensively browsed by the animals. Results of estimated dry season feed intake in one of the agroforestry treatments (treatment 2 with shrubs and pasture) using the *n*-alkanes techique, indicated that around 50% of the diet was provided by the shrubs (see Chapter 6). In contrast to the dry pasture the green shrub leaves may provide high levels of nitrogen, possibly resulting in more protein passing through the rumen without being fermented, thus increasing amino acids available for absorption in the small intestine and consequently higher milk yield (Mangan, 1988; Leng et al., 1992b). Tannins, in the moderate levels found in shrub species in this experiment (Section 6.4.2), may also protect protein from rumen degradation (Baba et al., 2002). Protein that escapes from the rumen may increase voluntary feed intake and improve the efficiency of use of energy and nutrients in the grass (Flores et al., 1979).

Supplementation of low quality forage with fodder from leguminous trees has been shown to increase the amount of plant protein available for absorption in the intestine of cows (Norton, 1994). The role of trees and shrubs as a vital component in livestock productivity is well recognized and particularly species such as *Leucaena leucocephala* and *Gliricidia sepium* have been widely used as supplements to basal diets around of the tropical world (Garcia et al., 1996; Alayon et al., 1998), the nutrient value of indigenous browse plants are now the subject of research in many areas with pronounced dry periods (Frutos et al., 2002). In this study milk yield was 13% higher in the agroforestry treatments than the open grasslands. In other studies the increase in dry season milk yield for cows grazing *Cynodon dactylon* supplemented with *L. leucocephala* has been reported to be in the order of 17% (Saucedo et al., 1980). Suarez et al. (1987) found that milk yield of cows grazing *Digitaria decumbens* with 2 hours of access to a *L. leucocephala* fodder bank had 18% higher milk yield than cows grazing only *D. decumbens*.

In addition to purely nutritional effects, cattle may have received beneficial shade from trees in agroforestry treatments. Considerable work has shown that milk production in hot conditions is depressed because of a reduction in voluntary feed intake as environmental and body temperature increases (Maust et al., 1972). High temperatures can induce conception failure, early embryonic mortality and reduce lamb birth weight in pregnant ewes (Roberts, 1984). Young calves, pregnant and lactacting cows, are more susceptible to heat stress than other cattle, but Daly (1984) found that all classes of animals grazed for a greater proportion of the day and higher weight gains in shaded paddocks compared with unshaded paddocks in tropical Australia. The increases in milk yield in the agroforestry treatments of the present study are also consistent with

Davinson et al.'s (1988) study in upland tropical conditions in Australia, where cows with access to shade had 2 kg cow^{-1} day^{-1} higher milk yield than did animals without shade.

The results of this study, that in the wet season there was no response of milk yield in relation to the treatments, is consistent with the results of Mosquera and Lascano (1992). They found that in periods of high rainfall in CIAT-Quilichao (Colombia) there was no change in milk yield when the cows had access to higher quality fodder. This may be explained by the fact that cattle supplied with sufficient grass may prefer grazing to browsing. In this respect camels are classified as browsers, goats as intermediate selective feeders with preference for browse, sheep as non-selective intermediate feeders with preference for grasses and buffalos and cattle as grazers (McDowell, 1988, Schwart and Schafft, 1988). It is possible that in this study in the wet season selection and intake of the diet depended on the feeding behaviour of the animals, and in the wet season the cows could have spent more of the grazing time on grass. The work of Dicko and Sikena (1992) in the sahelian zone of Mali concluded that the preference of the cattle for grass rather than for browse was obvious in the wet season, when cattle spent more than 95% of their grazing time on grass despite the simultaneous availability of abundant browse. However, their work showed that browsing started to increase at the beginning of the dry season and browsing was greater in the cattle subjected to sedentary system management. This may indicate that there are preferences for specific plant species in relation to seasonal changes, suggesting that trees and shrubs could be more important and relevant in periods of grass scarcity.

7.4.2 Milk yield per hectare

Poor drainage in block 3 coupled with unusually high rainfall in 1999 (16% higher than the mean annual rainfall of 1995 to 1998, with 240 mm between November and December 1999) led to atypically high soil moisture in that block, so that plots in block 3 were able to maintain growth of herbaceous vegetation throughout the dry season, with consequent higher carrying capacity and so milk production per hectare than would generally be expected. It is also possible that the wetter conditions observed in block 3 inhibited the attack of *Cydamus spp.* (see Chapter 5), which contributed to diminished pasture production in the drier plots in blocks 1 and 2. As was mentioned previously, this research was focused on evaluating the impact of trees under seasonally dry conditions, so the analysis and the discussion is based on the more typically dry conditions occurring in blocks 1 and 2.

After removing block 3 in the analysis for milk production per hectare in the dry season, a planned contrast showed significant differences in milk yield per hectare between the agroforestry treatments and the control. The higher milk produced per hectare in plots where there was additional leaf biomass supplied by *Crescentia cujete*, *Gliricidia sepium*, *Leucaena leucocephala* (Figure 7.6; see also Chapter 5, section 5.3.3) and some of the arboreal species, especially *Guazuma ulmifolia*, is indicative that the inclusion of shrubs on grasslands can improve animal production in areas where seasonal variations diminish the availability of herbaceous biomass from grasses and legumes. Under farming conditions improvements in productivity such those found in this study may encourage farmers to adopt multistrata agroforestry alternatives to maintain more animals on their farms, rather than transfer them to low land, which incurs high costs in terms of labour and transport. However, these results would have to be validated under farming conditions before coming to definitive conclusions.

In the current research a higher diet quality in terms of nitrogen (as indicated in Chapter 6) had impacts on daily milk yield per cow in the agroforestry treatments. The additional shrub leaf biomass enhanced carrying capacity expressed as milk yield per hectare in both wet and dry seasons. There may be prospects of further increases in milk production in future, as the site develops and fruit supply from arboreal species becomes important, thereby increasing the amount of carbohydrate and hence energy in the dry season diet.

CHAPTER 8

GENERAL DISCUSSION AND CONCLUSIONS

8.1 INTRODUCTION

This final chapter discusses the achievements and limitations of this study and the implications for planning future research on silvopastoral systems in Colombia.

The research reported in this thesis shows that considerable progress has been made towards the overall aim of evaluating the role of trees and shrubs in improving the productivity of cattle production systems on seasonally dry pasture. The presence of trees already on pastures in the Caribbean region of Colombia has been characterised for the first time and farmer's were found to value a range of species for various productive and service functions and to have interest in increasing tree cover of species they considered desirable on their pastures. Initial experimentation, with a wide range of tree species in single tree plots at four and five years of age and up to a mean height of around 7 m, demonstrated large differences in tree water use and the pasture biomass around different species, indicating the importance of species choice for maintaining understorey productivity. From these preliminary studies, it was evident that three structurally and functionally different tree strata of interest to farmers could be discerned: leaf producing shrubs, fruit producing arboreal trees and timber trees (not contributing to cattle diets, but casting shade and of economic value to farmers).

A large field experiment comprising various combinations of these strata with grazed pasture was set up incorporating species diversity in each stratum. Initial results from the experiment have indicated that trees can be established on seasonally dry pastures at densities sufficient to produce considerable forage biomass without immediate reduction in pasture biomass. Furthermore, the growth of some shrub and tree species was higher in more structurally and species diverse systems than in less diverse configurations indicating benefits to overall productivity from complementary resource use in complex mixtures where complementary species are grown. Shrubs at an overall density of 625 ha^{-1} presented well over 100 kg ha^{-1} of standing forage DM in the dry season, compared with about 2 t ha^{-1} of herbage. The shrub biomass was in addition to the pasture biomass and although constituting only around 5% of the total biomass of forage, appeared from n-alkane measurements to have constituted about half of the feed intake of cattle at the height of the dry season, indicating increasing preference for browse by cattle as the dry season progressed. Furthermore, there was evidence from research on their nutritive value that the high nitrogen content of the shrubs fodder could lead to more efficient utilisation of the herbaceous forage because of improved rumen function. This was borne out by measurements of milk production per cow, which while unaffected in the wet season was 13% higher in the dry season in agroforestry treatments than in pasture controls, indicating a higher diet quality where trees were present. In addition to the improvement of productivity of individual animals, there was also a much higher carrying capacity on plots with shrubs over the pasture control, especially in the dry season, where over 50% more milk was produced per ha in plots with shrubs than the pasture controls. Fruit from the arboreal stratum could make a further significant contribution to dry season productivity in due course when the trees start producing significant quantities of fruit, but this can not be assessed until the trees are older.

These key findings are discussed in relation to each other in more detail below together with requirements for further research, on one hand to continue to monitor system productivity as the trees grow and strata become more distinct and, on the other, to understand controlling interactions amongst components within the system to facilitate extrapolation of these results to a larger range of species, sites and management regimes.

8.2 RESEARCH INTO FARMERS' KNOWLEDGE

A participatory survey of Colombian farmers' knowledge and practice revealed much greater and more deliberate use of trees on pasture than had been previously recognized.

This confirms that asking farmers about their current knowledge and practice is a useful prerequisite to the design of research that is relevant to their needs. Farmers' knowledge about trees and scientific consideration of the trees present in pasture in this study illustrated the importance of different functional roles of trees, occupying different strata particularly with respect to the production of fruit eaten by cattle the dry season as opposed to leaf browse. The resultant mulstistrata experiment derived from the survey incorporates greater structural, functional and species diversity than in previous approaches to silvopastoral research in Colombia, illustrating how research can be adapted to farmers' knowledge and circumstances.

The participatory study (Chapter 2) clearly shows that contrary to the previous perceptions of researchers in the Caribbean region of Colombia, farmers in this region already have strategies to use trees in their farming systems in order to:

- provide shade for cattle
- maintain livestock productivity in dry periods
- produce timber, and
- contribute more generally in terms of environmental benefits.

So, planning research taking into account the intrinsic characteristics of the tree species and farmers' existing knowledge and practices about them, has led to investigation of promoting multistrata silvopastoral systems as an alternative for sustainable production, that may combine increase in sustainable productivity while avoiding failures of technology adoption that have been common with previous technological interventions.

The survey included in this research provided the opportunity for the researcher to build trust in her personal relationships with farmers which, considering information contributed by farmers, led to a change in the researcher's perspectives about which species to include in the experimentation. For instance, the overall mean of leaf biomass production amongst shrub species shows that *Crecentia cujete* was more productive than *Gliricidia sepium* and *Leucaena leucocephala. C. cujete* was one of the species mentioned by farmers as one of the most important fodder resources, as it can be used as a producer of both leaves and fruits throughout the year. To date, data of feed intake of *C. cujete* had not been reported either from studies using metabolic crates or in field situations. However, from the survey results it was clear that farmers thought that *C. cujete* fruits and leaves were preferentially consumed by cattle. The subsequent experimental results of feed intake determined in this study using the *n*-alkane technique (see section 6.2.2 and 6.3.4) suggested that *C. cujete* was consumed at a higher rate by cattle than the other two shrub species, corroborating what farmers knew about this species. The above points are indicative of how information about fodder trees provided by farmers in Colombia can be of practical use for planners, researchers and extension workers as it has been found to be in smallholder cattle production systems in Asia (Walker et al., 1997) and Africa (Roothaert and Franzel, 2001). Analysis of local knowledge about tree species and the management of silvopastoral systems may be used to combine both scientific knowledge and farmers' knowledge where they complement each other, in the development of agroforestry research that builds on, rather than replaces, local knowledge and practice (Thorne et al., 1999). In the present research, farmers' knowledge was used to direct a fundamental on-station research agenda exploring the role of tree strata on productivity, commensurate with the state of our collective understanding about multistrata agrofroestry configurations. This contrasts with much of the research on local or indigenous knowledge (Sinclair and Joshi, 2000) that has sought to influence more adaptive on-farm research.

8.3 IMPLICATIONS FOR PLANNING FUTURE RESEARCH ON MULTISTRATA SILVOPASTORAL SYSTEMS

8.3.1 Establishment

Survival and growth of trees on established pasture was measured for various multistrata combinations. Results have demonstrated the importance of well-prepared seedbeds and clean cultivation during the year of the establishment. The high survival rates (Sections 4.3.2 and 4.4.1) have led to successful establishment of the nine shrub and tree species, demonstrating the feasibility of establishment of silvopastoral systems in seasonally dry pastures.

The present research also provides data for growth of three timber species (*Pachira quinata*, *Swietenia macrophylla* and *Tabebuia rosea*) that have not been reported before in silvopastoral conditions in the Caribbean region of Colombia. Mean heights and diameters (sections 4.3.3c,d and 4.3.4c) are indicative of these species achieving high growth rates under the relatively fertile soil conditions on grazed pastures, and suggest that they are suitable to be planted in silvopastoral systems, since there was no evidence of detrimental effects of grazing on the development of these species.

Survival and growth rates of trees are likely to be important factors in determining whether farmers decide to plant trees on pastures. There is also, though, a need for specific research on farm establishment methods. In this regard it is important to evaluate farmers' perceptions not only about establishment methods but also about tree protection methods that may result in pastures with newly planted or regenerated trees being able to be utilised for grazing sooner than was achieved in the present study. This would result in a faster return to the investment in the system. Another option might be sequential development of tree resources on small areas within a pasture rather than doing it all at once. Lack of funds to build cattle drinkers and provide simple protection for the timber trees was the main factor that delayed the grazing of the present multistrata treatments from February to June 1999. This was an experimental artefact as there was sufficient tree height and biomass to begin grazing several months earlier, but nevertheless still implied resting or mechanically cutting the pasture for a year. It is also now a priority to study the development of tree species across a range of on-farm conditions, especially those with lower fertility, to determine the extrapolation domain for different planting options and obtain feedback from farmers regarding practical aspects of tree planting and early management.

8.3.2 Diversity and primary productivity

Combinations of a diversity of life forms are typical of many traditional agroforestry systems in the tropics (Nair, 1989). However, to date no data of growth variables of *Crescentia cujete*, *Gliricidia sepium*, *Leucaena leucocephala*, *Albizia saman*, *Cassia* *grandis* and *Guazuma ulmifolia* associated with pasture and in multistrata species assemblages have been reported. In this context the study provides valuable information for future establishment of multistrata silvopastoral systems. The most remarkable result in the multistrata silvopastoral research is the enhanced growth of shrubs and arboreal trees in the more complex multistrata treatments 4 and 5 than in treatments where only a shrub (treatment 2) or arboreal (treatment 3) stratum was combined with pasture (Sections 4.3.3a, 4.4.4a,b and 4.4.2.2). Similarly to growth results, overall shrub leaf biomass was higher in the multistrata vegetation assemblages than where only a shrub stratum was mixed with pasture. Both growth and leaf biomass results of this study confirm the generalization that a relative yield advantage (i.e. higher total productivity per hectare) is usually obtained from a polyculture as compared to that obtainable from monocultures (Vandermeer, 1981; Haggar and Ewel, 1997). Having the opportunity of measuring interactions amongst five contrasting groups of species, the research in the multistrata site should go on to look at the sustainability of these alternative systems assessing longer term productivity, as influenced by complementarity and interference for resource use in the different combinations and also by the contrasting species phenologies and spatial utilisation of atmosphere and soil, which indicate a potential for different resource capture capabilities. This implies a need for basic research through measurements of above and below ground net primary productivity and capacity to capture resources (light, water and nutrients) through development, retention and activity of tree leaf area and root length (Anderson and Sinclair, 1993). This type of research is important for understanding why and under what climatic and edaphic conditions various species combinations may be most appropriate for increasing livestock production under various farm conditions. Understanding the extent to which the underlying mechanisms of interaction can be manipulated by human intervention, such as defoliation induced by pruning or adjusting browsing pressure, is also vital for informing management of complex species assemblages (Sinclair et al., 2000). It is clear that understanding physiological principles of interaction may be a more feasible way to assist farmers and researchers make decisions in determining for a particular set of environmental conditions the densities, type and number of species to be included in the system, rather than attempting to test a very large numbers of species assemblages across an array of site types. This illustrates a way in which research on complex agroforestry systems differs from conventional approaches to agriculture and forestry based on single species stands or simple mixtures.

8.3.3 Nutritive value of leaf biomass

In this thesis the nutritional role of shrubs and arboreal trees in seasonally dry pasture was evaluated initially through leaf biomass measurements for the shrubs and determination of nutritional values of both shrub and arboreal species through their nitrogen, tannin contents and potential degradability. The amount of leaf biomass produced by the shrubs through the year indicate their suitability for silvopastoral systems (see Figure 5.6; Section 5.3.3). Leaf biomass in the dry season 2000 when the scarcity of pasture was dramatically affected by season was over 100 kg ha^{-1}, and the importance of the availability of this fodder at that time was corroborated in the results of a feed intake study that indicated that approximately 50% of the animal diet was supplied by the shrub species. Consistent with the height and stem diameter growth results, leaf yield of shrubs was higher in the more complex treatments 4 and 5. Although *Gliricidia sepium* and *Leucaena leucocephala* have been screened for many uses, ranging from alley cropping and fodder banks to live-fences, leaf yields of these two species and *Crescentia cujete* has not been reported under mixed systems and browsing conditions. The production of forage of tree species remains a priority almost everywhere in the tropics. Therefore this study provides important information of the shrub production under different competitive arrangements that could be useful for farmers not only from the Caribbean region but also for those ecosystems with similar characteristics. However, these shrub species vary in phenology, architecture and morphology which may explain their different ability to produce leaf biomass in relation to different availabilities of above and belowground resources. It was clear that *L. leucocephala* performed similarly regardless of what other species it was associated with. In contrast, *G. sepium* was more productive where the shrub stratum was partially substituted with arboreals and pasture, and *C. cujete* most productive in the most complex multistrata system involving shrubs, arboreals and timber species. It is now important in the future to explore whether these patterns of leaf biomass production being more productive for some species in the more complex treatment is affected as arboreal and timber crowns extend. It would be useful to measure biomass allocation to roots, stem and leaves in relation to resource capture in order to understand trade-offs between leaf productivity and competitive effects.

In addition to the leaf biomass production another factor determining the suitability of shrub and arboreal species for silvopastoral systems is their nutritional value. With regard to this, the nitrogen content of all species studied was sufficiently high and not prone to fluctuate with season, making them complementary to pasture as a supplement to the poor quality dry season pasture. Tannin contents indicated that only one of the arboreal species (*Cassia grandis*) had levels higher than 5%, and estimates of feed intake of shrubs showed that almost half of the diet was supplied by them, indicating that there was no evidence of anti-nutritional factors limiting feed intake.

In many pastoral areas of the world, the basic resource is pasture, which is generally low in total protein and fermentable nitrogen. Nutritional research has shown that large increases in animal productivity and efficiency can be brought about by small changes in the balance of nutrients in the feed base (Leng, 1990). In grasslands, particularly in dry areas, leaves, seeds and fruits from shrub and arboreal species, represent by far the greatest potential source of protein that can be used as supplements to provide soluble nitrogen, by pass protein and a source of minerals for cattle diets (Leng et al., 1992a). In this research, the most remarkable result from dry matter degradability was the considerable improvement in potential degradability of *Dichanthium aristatum* associated with the multistrata vegetation mixtures than where only pasture was consumed in the control. This result corroborates Leng's statements (op. cit.) and it also illustrates the large potential impact of tree fodder to create a rumen environment more capable of fermentative digestion of poor quality forage. It is also possible that in this study associative effects may have occurred between components of the mixed diet (herbaceous and shrubs) as a consequence of the interactive process of the nutritional value of the mixtures (Rosales and Gill, 1997). In this context further research by studying the fermentative rates, to characterise these effects in terms of the times at which the synchrony occurred and in terms of the fermentability of the components (Rosales and Gill, 1997) should be conducted in the multistrata experiment.

In this study the ammonia levels that were consistently higher in the treatments where *D. aristatum* showed higher potential degradability, confirms this. Taken together, the degradability and ammonia results are indicative that the efficiency of microbial growth may have been improved by nutrients supplied by the shrubs and at least one of the arboreal species that was extensively browsed (*Guazuma ulmifolia*). The indication of improved dry season diet quality, where trees were introduced to pasture, were confirmed by higher milk productivity per cow in agroforestry plots than controls (Section 7.3.1).

In terms of nutrition research the multistrata experimental site will offer great potential to explore relationships between the protein/energy ratio of diets to the efficiency of feed utilization when the arboreal species begin producing significant quantities of fruits. In the present research there was no attempt to identify deficiencies in micro and macro minerals in the different diets. So, further research is necessary to identify and provide information about critical nutrients that may be deficient in the diet and therefore identify management strategies, including species choice, fertilisation or feed supplementation that may optimise nutrient supply in relation to animal requirements. It is possible that the response in terms of degradability of some of the components of the diet in these systems may have been influenced by physiological and ecological interactions occurring amongst trees within the system, it is therefore, important to consider competitive relationships between species in relation to nutritional responses as well as primary productivity in future research.

8.3.4 Feed intake

Prior to the present research, there was not published information on the use of the *n*-alkane method to determine both diet composition and feed intake of complex diets in the tropics for large ruminants grazing and browsing mixed herbaceous vegetation and shrub species. The results reported in Chapter 6 suggest the suitability for evaluating feed intake of a large number of herbaceous and browse species in silvopastoral systems. Other methods that have been developed to estimate the amount of grass or herbaceous legumes eaten by grazing animals may be unreliable because they cannot be analysed as discrete compounds, and because incompatibility in their analyses in herbage and faeces can lead to errors in the estimation of digestibility and intake (Langlands, 1975). Therefore the *n*-alkane method appears to be more accurate than previous methods for estimating intake in grazing animals; it also accommodates differences in herbage digestibility occurring in individual grazing animals (Dove and Mayes, 1996). Future research should be planned to expand the evaluation of this technique to include a wider range of browse species including fruits of arboreal trees that may make an important contribution to cattle diets at key times in the season.

8.3.5 Effects of trees on pastures

The effects of introducing trees on established pasture were addressed through the studies described in Chapters 3 and 5. The measurements of tree pasture productivity and resource use on single tree plots shows that although drainage conditions and seasonal effects are important factors influencing pasture productivity, effects on total herbaceous biomass production differed markedly amongst the different tree species. In addition to the incorporation of farmers' knowledge, further research should take into account the large differences that can be found in pasture biomass associated with different tree species. Those differences are likely to be associated to some extent with the different crown and root architecture of the tree species, which affects light transmission, rainfall interception, water use, evapotranspiration and soil nutrient uptake, that are factors influencing pasture productivity.

Consistent with the results in the single tree plot study herbage production in the multistrata silvopastoral systems varied with the rainfall, corroborating that the availability of water is the overwhelming factor determining plant growth in dry environments (Le Houérou, 1984). Herbaceous biomass was assessed throughout two years, and although the results described in Chapter 5 did not show detrimental effects of the trees either on productivity or in changes in botanical composition, it would be not appropriate to draw firm conclusions because additional interactions may occur over a longer time as the trees grow and become more dominant at the site. It is important to identify the most productive tree-grass associations and to determine the most important factors (such as shade or soil fertility) governing understorey herbage production and forage quality. This information may be achieved by comparing dry matter yields and forage quality amongst treatments, comparing soil fertility and light intensity levels between crown and open areas; and relating soil fertility parameters, tree standing biomass and light intensity to forage production and quality. Such an approach should help researchers to gain a better understanding of the complex interactions in silvopastoral systems, and to optimise and stabilise forage productivity.

8.4 IMPLICATIONS FOR ANIMAL PRODUCTION

It is recognised that the primary constraint in animal production based on tropical grasses is poor nutrition and subsequently this factor leads to unsustained and inefficient production systems. Farming systems in the Caribbean region of Colombia as shown and discussed in Chapter 2 are not an exception. Estimated losses in milk and beef yield range from 41% to 73% as a result of the low dry matter of forage in the dry season and the lack of appropriate technologies to improve productivity under those conditions. This research addressed farmers' desire to explore feeding strategies using the existing regional resources. Thus, this study shows results of the effects of shrub and arboreal species on animal production through assessments on milk yield and carrying capacity. While there was no effect of trees on productivity of individual core cows in the wet season, carrying capacity and hence milk production per unit area was slightly higher in agroforestry treatments than pasture controls. Much more importantly, in the dry season, when the feed intake studies suggest that a large proportion of the cattle diet was coming from shrubs, both individual productivity of cows and production per unit area were substantially increased. The increase in individual milk yield of cows (13%) confirms indications of improved diet quality and rumen function, suggested from the studies of nutritional quality of browse in Chapter 6. However, in the farmers' context it is important not only to maintain the average of daily milk yield, but also increase milk production per hectare. The results clearly show that milk yield per hectare as a result of an increased carrying capacity offered by the availability of higher biomass in the agroforestry treatments was much higher (by 50%) than that in the control plots. Therefore, the results of milk yield per hectare suggest that inclusion of shrub and arboreal species can contribute to alleviation of the nutritional constraints of the dry season conditions.

Up to the present time there are no data about the cost for farmers in the Caribbean region of their transhumance practice, or of its environmental implications for the Magdalena and San Jorge basin systems, that have to carry most of cattle from Sabanas and Valle del Sinú microregions for key parts of the dry season. In this study, the higher carrying capacity of agroforestry systems over the pasture only control plots indicate that even only the inclusion of shrubs can provide an impetus to farmers to adopt silvopastoral systems. There may also be further knock-on effects of improved reproduction, lowered puberty of heifers and shorter intercalving intervals and further improvements to cattle nutrition when fruit from arboreal trees starts contributing to dry season cattle diets and timber and arboreal species cast more even overhead shade. It is critical both to continue research at the site to explore these effects, as the systems mature, as well as to conduct on farm research with promising combinations of species to confirm results under farm conditions and incorporate farmers reactions to incorporation of trees on pastures .

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Appendix 2.1. Description of Agroecological Zones of the Caribbean region (West of the Magdalena River)

C: Marine terraces that correspond with the coastline, rarely exceeding 50 m above sea level. The water table is high and often saline, in many places is bordered by marshes and mangrove forest and with sediments carried by coastal currents. The dominant soils in these areas are Gleyic Solonchaks (often with mangrove vegetation), these have a very high aluminium saturation. These soils are rather unsuitable for agriculture and should be conserved as protected areas.

Cf: Typical areas of the Atlantic department. Luvisols are commonly found. Soils are fine textured and fertility levels are usually low to medium. Slopes less than 12%. More suitable for grassland but adapted crops such as maize, sesame and cotton grow well.

Cj: Alluvial plains derived from sedimentary materials, fertility levels are medium to high and they are generally well drained. Slopes less than 7%. Luvisols are the major soils of this zone. Crops, which can be grown, include cotton, maize, sorghum, sesame, cassava and fruits. Land more suited to cropping than grazing.

Cn: Alluvial plains that are flooded in the wet season. The soils mainly are fluvisols. The suitability of these soils depends mainly on their fertility status and their risk of inundation. More suitable for grassland than cropping.

Co: Alluvial plains with soils derived from sedimentary rocks. Slopes less than 7%. Well drained, low fertility and high aluminium saturation, most of them covered either by forests, savannas or grassland. Some areas are used for extensive grazing.

Cp: Areas with soils from sedimentary materials. The soils of these areas are limited by high contents of salts and sodium and severe erosion.

Cu: Hilly lands in the Caribbean plains, upper and lower Magdalena river, with undulating to broken relief and slopes as steep as 25%. Soils are developed from sedimentary materials, and are little developed. Profiles are shallow to moderately deep. Well drained, of moderate fertility and susceptible to erosion. Locally affected by sodium and/or other salts. Most of these areas are covered by savannas or grassland. The major area is used for extensive grazing. Deficiencies in phosphorus, potassium, copper and cobalt are probably widespread. The major soils are Acrisols and Luvisols. More suited to extensive cattle raising than cropping.

Cv: Soils of these zones are derived from heterogeneous materials, and are little developed and shallow. Soils are well drained. The most important problem is the strong susceptibility to erosion, which requires careful management. These areas have restricted suitability for grazing and cropping. They should be taken as conserved areas.

Kb: Alluvial plains. Soils commonly derived from sedimentary materials, well drained with medium to high fertility. The soils of these zones are much used for agriculture due to favourable physical properties and low slopes (less than 3%). Excellent possibilities for the use of mechanical equipment. Principal crops for these soils are cassava, sugar cane, maize, fruits, banana, plantains, sorghum and cotton.

Kr: Upland with slopes as steep as 25%. Soils derived from sedimentary rocks and little developed. Well drained. Low fertility. Grazing and cropping are feasible.

Ku, Kv: These areas are predominantly of steep topography with some high mountains (slopes of 20% to > 50%). Soils are, in general, well drained. Low fertility and strong risk of erosion. The best uses of these areas are for forestry, wildlife and recreation.

Mg, Mj, Mk: Steep land with slope more than 50%. Well drained and low fertility. Soils are derived from volcanic materials. The soils are rather unsuitable for traditional agriculture because of steepness and stoniness but forestry will do well.

W: These areas include the humid lowland with alluvial plains and marine terraces. The natural vegetation consists principally of tropical evergreen forest with coastal fringes of mangrove forest and swamp forest. Drainage is the greatest problem in these areas.

Source: Instituto Geografico "AGUSTIN CODAZZI" (IGAC), 1987.

Appendix 2.2. Questionnaire used to collect information about farmers' knowledge about trees in the Caribbean region of Colombia (West of Magdalena river).

1. Name of interviewee______________ Owner ( ) stockman ( ) Age________

Years at the farm___________Occupation________________

Farm name______________________Total area_________

[1] / Location: 1 ( ), 2 ( ), 3 ( ), 5 ( )

Altitude_________

Agroecological zone:________

Size of farm: <50 ha. ( ) 50-100 ha. ( ) > 100 ha. ( )

Marital status: married ( ), single ( ), widow ( ), divorced ( )

Education Level: Primary school______High school ______ University _______

Family members

Adults	Children	Female	Male	Occupation

2. Land Use:

Type use	Area % ha.
Livestock	
Crops grown	
Forest	
Other (specify)	

Farm sketch: (To draw a map - best done with the farmer, same with classifying land types he/she recognises)

---

[1] / = Litoral; 2 = Golfo de Morrosquillo; 3 = Sabanas; 5 = Valle del Sinu

Tree inventory for each type of land

<table>
<tr><td></td><td colspan="60">TYPE OF LAND</td></tr>
<tr><td></td><td colspan="30">TYPE A</td><td colspan="30">TYPE B</td></tr>
<tr><td>Total ha</td><td colspan="30"></td><td colspan="30"></td></tr>
<tr><td>Total of trees</td><td colspan="30"></td><td colspan="30"></td></tr>
<tr><td>Number of species</td><td colspan="30"></td><td colspan="30"></td></tr>
<tr><td>Location of the trees</td><td colspan="6">[2]DTF</td><td colspan="6">CF</td><td colspan="6">DPSLA</td><td colspan="6">SB</td><td colspan="6">PLFS</td><td colspan="6">DTF</td><td colspan="6">CF</td><td colspan="6">DPSLA</td><td colspan="6">SB</td><td colspan="6">PLFS</td></tr>
<tr><td></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td><td colspan="6"></td></tr>
<tr><td>[3]Name of species</td><td colspan="30">USES</td><td colspan="30"></td></tr>
<tr><td></td><td colspan="5">Brow</td><td colspan="5">Shade</td><td colspan="5">Hedg</td><td colspan="5">Wood</td><td colspan="5">Fuelw</td><td colspan="5">Other</td><td colspan="5">Brow</td><td colspan="5">Shade</td><td colspan="5">Hedg</td><td colspan="5">Wood</td><td colspan="5">Fuelw</td><td colspan="5">Other</td></tr>
<tr><td></td><td colspan="30"></td><td colspan="30"></td></tr>
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<tr><td></td><td colspan="30"></td><td colspan="30"></td></tr>
<tr><td>Obsevations</td><td colspan="30"></td><td colspan="30"></td></tr>
</table>

3/ Questions to ask:

Name of the trees
How do you use each species?
Is it eaten by livestock?
What do you know about its feeding value? (palatability and or/toxicity, toxic stage/season, effects on livestock)
Do you know when is in leaf, fruit and flower?
Do you manage it? If yes, how do you do it?
Are there any other trees you think are important? If yes and then list then and collect information on those.

1. LIVESTOCK HOLDING

Type of use	Area % ha.
Dual Purpose Cattle	
Beef Cattle	
Sheep	
Goat	
Other (specify)	

1.1. HERD COMPOSITION

Type	Number
Cows	
Calves	
Heifers	
Steers	
Bulls	

---

[2] / DTF = Dispersed through the field; CF = One corner of the field; DPSLA = Dense patches in several low lying areas; SB = Steep banks; PLFS = Patches of less fertile soil.

2. HERBACEOUS FORAGE RESOURCES

Type	Area % ha	Name
Native grass		
Improved grass		
Native legumes		
Improved leg.		

3.1. What do you do during the dry season to face up the scarcity of pasture biomass?

Animals are sold to reduce the carrying capacity	
Animals transhumance to wetland	
Provide alternative feed	
Hire pasture land	

3. FODDER TREE RESOURCES AND USES

3.1. Is there any time when pasture biomass is less than required by livestock?

If yes, then

3.1.1. When does it occur? ________________________ What do you do about it?

____

____

3.2. Which tree species do you prefer not to have on your farm and why?

Species	Reasons

3.3. Have you planted trees yourself? Or deliberately allowed natural regeneration to take place?

Yes ( ) No ( )

3.3.1. If yes, Why did you plant/allow natural regeneration of the trees?

____

____

3.3.2. How have these trees grown ?

Species	Seed	Seedling	Cutting	ENR*	Other

*Encouraged natural regeneration

3.4. Do trees affect pasture grasses?

If yes, how ? and do all trees affect pasture in the same way and to the same extent? If no,

3.5. Which tree species or type of trees do you think affect pasture most and why?

Species	Reasons

3.6. Are grass species all affected by trees in the same way and to the same extent and why etc.

Grass species	Reasons

4. FODDER USE

4.1. Which species do think are most preferred by cattle?

Fodder species	Reasons

4.2. Do you use tree fodder?

4.3. What potential do you think there is for using tree fodder to supplement cattle diets?

4.3.1. What constraints are there to using tree fodder to supplement cattle diets?

4.4. What do cattle eat during the rainy season?

____

____

____

4.5. Which tree fodder species do you think are nutritious or less nutritious to animals and why?

NUTRITIOUS FODDER SPECIES	REASONS	LESS NUTRITIOUS FODDER TREE SPECIES	REASONS

5. TREE FODDER MANAGEMENT

5.1. Does any body lop fodder trees on your farm?

If yes, who does it? ______________________________

How__________________________ When? ___________________________

5.2. What criteria do you use to decide which fodder trees to lop at a particular month ?

____

Appendix 2.3 List of tree and shrub species found in pasture of the Caribbean region. Species are ordered by alphabetical Latin names.

Species Latin name	Local name
Acacia farnesiana (L.) Willd.	Aromo
Albizia lebbeck (L.) Benth.	Viva seca
Albizia saman (Jacq.) F. Muell.	Campano
Albizia caribaea (Urban) Brilton & Rose	Guacamayo
Albizia sp.	Tabaco
Anacardium excelsum (Bertero & Balb.) Skeels	Caracoli
Anacardium occidentale (L.)	Marañon
Aspidosperma polyneuron Muell. Arg.	Carreto
Bactris guineensis (L.) H.E. Moore	Corozo, hoja de lata, palma' lata o corozo
Bombax septenatum	Bonga
Bulnesia arborea (Jacq.) Engl.	Guayacan
Bursera simarouba (L.) Sarg.	Siete cueros
Caesalpinia coriaria (Jacq) Willd.	Dividivi
Calliandra calothyrsus Meissr	Carbonero
Calliandra emarginata Benth.	Carbonero
Capparis odoratissima Jacq.	Olivo
Carludovica palmate R & P.	Palmiche
Castilla elástica Sessé	Caucho
Cassia emarginata L.	Cuchillito
Cassia grandis L.f.	Caña fistula
Cassia siamea (Lam.) Irwin & Barneby	Abeto
Cecropia peltata L.	Guarumo
Cedrela odorata L.	Cedro
Ceiba pentandra (L.) Gaertn.	Bonga
Citrus limón (L.) Burm. f.	Limon
Citrus sinensis (L.) Osbeck.	Naranja
Coccoloba pubescens L.	Uvero
Cordia	Canalete
Cordia	Solera
Cordia alliodora (R.&P.) Cham.	Vara de humo
Cordia alba (Jacq.) Roem. & Schult.	Uvito
Cordia sebestena L.	San joaquin, chichero
Crateva tapia L.	Naranjuelo
Crescentia cujete L.	Totumo
Enterolobium cyclocarpum (Jacq.) Griseb.	Orejero o carito
Spondias mombin L.	Hobo
Erythrina fusca Lour.	Chengue
Ficus carica L.	Higo
Gliricidia sepium (Jacq.) Walp.	Matarraton
Gmelina arborea Roxb.	Melina
Guadua angustifolia Kunth	Guadua
Guaiacum officinale L.	Guayacan de bola
Guazuma ulmifolia Lam.	Guacimo
Hura crepitans L.	Ceiba blanca o de leche
Hymenaea courbaril L.	Algarrobo
Inga sp.	Guamo
Lecythis minor Jacq.	Olleto, olla de mono

Species Latin name	Local name
Jatropha curcas L.	Piñón
Ocotea sp.	Cainmancillo
Lonchocarpus sp.	Sangregao
Maclura tinctoria (L.) Steudel	Mora
Malpighia glabra L.	Cereza
Mangifera indica L.	Mango
Melicoccus bijuglatus Jacq.	Mamon o mamoncillo
Pachira quinata (Jacq.)	Ceiba roja o tolua
Platymiscium pinnatum (Jacq.) Dug. Griseb. & H.L. Wendl.	Trebol
Ponteria sapota (Jacq.) H.E. Moore and Stearn	Nispero
Prosopis juliflora (Sw.) Dc.	Trupillo
Pseudobombax septenatum (Jacq.) Dug.	Majagua, jagua
Psidium guava L.	Guayabo
Rivina humilis L.	Coralillo
Sabal mauritiiformis (H. Karst.)	Palma amarga
Sapindus saponaria L.	Pepo
Sapium aucuparium Jacq.	Piñique
Scheelia excelsa Karst.	Palma de vino
Senna spectabilis (Dc.) Irwin & Brneby	Vainillo o velero
Sterculia apelata (Jacq.) H. Karst.	Camajon
Tabebuia billbergii (Bureau) K. Schum.	Polvillo o amarillo
Tabebuia chrysea Blake	Cañaguate
Tabebuia rosea (Bertol.) A.Dc.	Roble
Talisia oliviformis (Kunth.) Radlk.	Mamon de mico
Tamarindus indica L.	Tamarindo
Tectona grandis L.f.	Teca
Tibouchina lepidota Baill.	Siete cueros
Trichanthera gigantean (Humb. & Bonpl.) Nees	Palo de agua
Triplaris sp.	Volador, roble rosado
	Santacruz
	Estribo
	Campano de bledo
	Muñeco
	Aceituno
	Mapurito
	Rabo de iguana
	Aji
	Volao
	Guayaba agria
	Coco
	Bolombolo
	Cenicero
	Changao
	Chicho

Appendix 3.1. List of herbaceous species found in pasture of Turipaná research centre. Species are ordered by alphabetical Latin names.

Species Latin name	Local name
Achyrantheis aspera L.	Cadillo rabo de rata
Aeschynomene brasiliana (Poir.) DC.	
Amaranthus dubius Thell.	Bledo de cerdo
Amaranthus spinosus L.	Bledo espinoso
Bidens pilosa L.	Amor seco
Blechum brownie Ant. Juss.	Camaroncillo
Brachiaria mutica (Forssk.) Stapf	Admirable o pará
Borreria laevis (Lam.) Griseb.	Cansamozo (hierba toro)
Caperonia palustris (L.) St. – Hill	Caperonea
Centrosema macrocarpum	Centrosema
Centrosema pubescens Benth	Centrosema
Chamaesyce hypericifolia (L.) Millsp.	Lechosa
Chamaesyce hirta (L.) Millsp.	Tripa de pollo
Cleome spinosa Jacq.	Jazmin del río
Commelina diffusa Burm. f.	Santa Lucia
Cucumis anguria L.	Patilla de golero
Cucumis melo L.	Meloncillo
Cynodon dactylon (L) Pers.	Sabana
Cynodon nlemuensis Vanderyst	Pasto estrella
Cyperus odoratus L.	Cortadera
Cyperus rotundus L.	Coquito
Desmodium uncinatum (Jacq.) DC.	Pega pega
Dichanthium aristatum (Poir.) C.E.Hubb.	Angleton
Echinochloa colona (L.) Link	Liendra de puerco
Eclipta alba (L.) Hassk.	Botoncillo
Eleusine indica (L) Gaertn.	Pata de gallina
Heliotropium indicum L.	Berbena o rabo de alacran
Ipomoea hirta Mart. & Gal	Batatilla
Jatropha urens L.	Pringamosa
Malachra alceifolia Jacq.	Malva
Melampodium divaricatum (L.C. Rich.)DC.	Boton de oro
Momordica charantia L.	Balsamina
Mucuna deeringiana	Vitabosa
Mucuna pruriens (L.) DC.	Pica pica
Panicum maximum Jacq.	Guinea
Paspalum fasciculatum Sw.	Gramalote
Paspalum conjugatum Berg.	Hierba agria
Paspalum virgatum L.	Pajon
Phyla nodiflora (L.) Greene	Cidron
Physalis angulata	Topotoropo
Portulaca oleracea L.	Verdolaga
Priva lappulacea (L.) Pers.	Cadillo de bolsa
Rottboellia cochinchinensis (Lour.) Clayton	Caminadora
Rhynchosia minima (L.) DC.	Frijolillo
Ruellia tuberosa L.	Espanta suegra
Sarcostemma galucum H.B.R.	Bejuco de sapo
Scheelia excelsa Karst.	Tumbaburro
Setaria geniculata (Lam.) P. Beanv.	Limpia frasco
Sorghum halepense (L.) Pers.	Jhonson

Continued

Appendix 3.1. List of herbaceous species found in pasture of Turipaná research centre. Species are ordered by alphabetical Latin names.

Species Latin name	Local name
Teramnus uncinatus (L.) Sw.	Teramnus
Tibouchina lepidota Baill.	Sabana
Vigna sp.	Vigna
	Escobilla
	Uña de gato
	Patilla de culebra
	Cocorilla
	Orozú
	Guayabito
	Atarrayo
	Bejuco de agua
	Pajocillo
	Botoncillo
	Tomate de Diablo
	Albaca cotorrona
	Limpia frasco
	Campanita
	Escoba blanca
	Anisillo
	Ahuyama
	Bola de gato
	Manca tigre
	Tres bolas
	Venturosa
	Altamisa
	Canutillo
	Esponjilla
	Azotapinga
	Santa María
	Peinecillo

Appendix 4.1. Overview of the shrub, arboreal and timber species used in the multistrata silvopastoral sytems.

a) *Crescentia cujete* (local name totumo), belongs to the Bignoniaceae family, it is found from Mexico through Central and South America. It is small or medium-sized tree, usually 10 m high or less with thick trunks, with spreading branches and broad head; leaves nearly sessile, clustered at nodes, oblanceolate, to 15 cm long, flowers 5 cm long, corolla yellowish with red or purple veins, lobes lacerate. Fruits are very variable in size and shape, may be up to 30 cm in diameter, and while initially heavy with wet pulp and seeds, dries hard, remains smooth, and becomes quite light. The fruits are very important throughout Central and South America, where they have been used since ancient times for various purposes. The wood is light brown or yellowish brown. The wood is used for tool handles (http://florawww.eeb.uconn.edu; http://www.botany.hawaii.edu).

b) *Gliricidia sepium* (local name matarratón), is truly multipurpose tree, nitrogen fixing tree species, with many documented uses in tropical farming systems. It is used throughout the tropics for fuelwood, living fences, plantation shade, plant support, green manure, fodder, medicinal and other products and services (Loren, 1987). Although originating in Central America, *G. sepium* grows in various parts of the tropics from sea level to about 1600 m elevation, but mainly below 500 m (Kang and Mulongoy, 1987). According to Glover (1987), best growth is obtained on well drained fertile soils, although satisfactory growth rates have been observed on eroded land with poor and acidic soils. Values reported for *G. sepium* leaf dry matter generally ranges from 2 t ha $^{-1}$ year $^{-1}$ (Wong and Sharudin, 1985) t ha^{-1} year^{-1}. However Stewar *et al.*, (1992) stated that in many cases *G. sepium* can yield as much as or more biomass than *Leucaena leucocephala*. Espinoza (1984) showed that the crude protein level of *G. sepium* could vary from 10 to 30% depending on the plant parts analysed (leaves >petiolos>branches) and their position on the branch (apical>middle>inferior), its dry matter digestibility has been found around 57.9%, NDF between 48 and 51% and ADF between 33.64 and 37.42 % (Roldan 1981; Kass and Rodriguez 1987, Nitis et al., 1987).

c) *Leucaena leucocephala* (local name leucaena), is a fast-growing, multipurpose tree native to Mexico lands (Brewbaker, 1987, Sorensson, 1989) and Central América (Duke, 1981) and now cultivated in many tropical areas. Aproximately 2-5 million hectares are planted to *L. leucocephala* worlwide, making it one of the most widely disseminated fuelwood and fodder crops (Brewbaker and Sorensson, 1990) and in some countries it is used for extensive grazing cattle (Humphreys and Partridge, 1995). *L. leucocephala* is also planted as a living fence for livestock and, as a source of mulch. As a memeber of the legume family, it is also performs the valuable function of enriching the soil with nitrogen (Brewbaker and Sorensson, 1990). Generally, annual DM yields are 2 to 30 t ha^{-1} year-1 (NAS, 1977; Jones, 1979; Shelton and Brewbaker, 1994). It is among the highest quality fodder trees in the tropics (Brewbaker, 1986). Herbage taken at peak quality has the following percentages values of dry matter: digestibility 55-70%, crude protein 20-25, N-free extract 30-50 (fibre 25-35, NDF 20, ADF 15, cellulose 10, ligning 5), mimosine 1.5-2.5 and tannins 1.5-2.5 (Pound and Martinez-Cairo, 1983; Jones, 1979; Brewbaker and Hutton, 1979). An advantange of Leucaena is that leaves remain green long into the dry season, when other forage species, such as grasses are scarced (Smith et al., 1992). Even though the potential of *L. leucocephala* as forage is well known, there has been concern about its effects on animal health. This has been related to mimosine, an amino acid found in *L. leucocephala*, and to DHP (3 hydroxi-4 (1H) pyridone), a metabolite of mimosine produced in the rumen, DHP affects the thyroid gland and can lower the level of thyroid hormone (thyroxine) in the blood and depress liveweight gain (Jones and Winter, 1982). However, if Leucaena is less than 30 percent of the feed, livestock usually do not suffer any ill effects from mimosine (Smith et al., 1992) and DHP appeared to be overcome by introduction of rumen bacteria capable of degrading DHP (Jones and Magarrity, 1986).

d) *Albizia saman* formerly classified as *Samanea saman* (local name campano, algarrobillo or saman), is indigenous to Central América, the West Indies, and north of South América. It is a nitrogen fixing species, of fast growing, which usually reaches a height of 30 m (Allen and Allen, 1981). It is found in the tropics from sea-level to 1000 m where the temperature is 20-35°C. *A. saman* is hardy indifferent to soil types (Allen and Allen, 1981). According to Hesleigh and Holaway (1988) this species grow best in moist, well-drained fertile soils. (Allen and Allen, 1981)., stated that *A. saman* grows equally well in sandy soils and heavy clays, and even in waterlogged placed by rivers. Normally it is found in neutral to mederately acid soils (Franco et al., 1995). The wood of *A. saman* is light weight, with density of 720-880 kg $m^{3\ -1}$, has a golden brown color with dark streaks, takes a fine finish, and is resistant to dry-wood termites (Allen and Allen, 1981). The timber is not harvested commercially because of the scarcity of timber stands. Its use is reserved for bowls, trays, carvings, furniture, handicrafts and other uses include fencing, construction timbers, plywood and the manufacture of crates, wheels and boats (Allen and Allen, 1981; NFTA, 1995). *A. saman* is a valuable component of pasture systems. Its shade protects livestock from the hot tropical sun. Its nutritious pods, which are an important dry-season fodder contain 12-18% crude protein and are 40% digestible (F/FRED 1994). The shade and nitrogen-rich leaf-litter of *A. saman* improve the nutritional value of understorey grass (Allen and Allen, 1981).

e) *Cassia grandis* (local name caña fistula) belongs to the *Caesalpinaceae* family. It has been reported as non-nodulating species (De Faria, 1989). *C. grandis* usually attains a height of 15 m; leaves are alternate and compound. The pods are large an the length is in general 20 to 25 cm and width 15-25 cm, and the seeds are covered by a sticky sweet-flavoured pulp which contains sugar, gum, impure tannic acid, coloring matter, a gluten-like matter and moisture. Mature pods are usually dark brown. The pods of *C. grandis* are one of the best resources for feeding animals during the dry season. A number of seed per kilogram is around 6,600. Its wood is hard and heavy and it is used for fuelwood, fencing and construction (http://www.ibiblio.org)

f) *Guazuma ulmifolia* (local name "guácimo), belongs to the family *Sterculiaceae* is a small to medium-sized tree which usually attains a height of 15 top 20 m., commonly multi-trunk of 30 to 60 cm and dense crown. It is indigenous to tropical America. Its oblong leaves are 6-12 cm in length and the tree produces small white to light yellowish flowers. It produces and edible fruits with a strong honey scent.

Fruits are warty, ellipsoid capsules, of 1.5-4.0 cm long and 1 to 2.5 cm wide. They are green and fleshy, but mature fruits are usually dark-brown. A tree can produce between 1.5 to 2.5 kg of fruits (unpublished date), and one kilogram can have approximately between 100000 to 220000 seeds (Vallejo y Oviedo, 1994). *G. ulmifolia* foliage and fruits are eagerly eaten by livestock (Janzen, 1982). The crude protein content of leaves and stems ranged from 16-23% and 7-8% respectively, and dry matter *in-vitro* digestibility of the leaves around 58% (Araya et al., 1994; Contreral et al., 1994; Ortega et al., 1998). Tannin content of 2.4% was reported by Araya et al. (1994) and 0.145 mg g^{-1} was found in leaves and 0.115 mg g^{-1} by Ortega et al. (1998). *G. ulmifolia* has had a place in herbal medicine in almost every country where it grows. The bark and the leaves are most used medicinally, however, sometimes the fresh root is employed. Alarcon-Aguilera (1998) showed *G. ulmifolia* as one of the useful plants to decrease the hyperglycaemic peak and/or the area under the glucose tolerance curve. Their results suggested the validity of its use in diabetes mellitus control. The antibacterial activity to control gastrointestinal disorders was reported by Caceres et al. (1990). *G. ulmifolia* has been studied as anti-fungal, antioxidant, anti-microbial, astringent, anti-ulcerogenic, cytotoxic, and depurative amongst other properties (www.rain-tree.com)

g) *Pachira quinata* (local name "ceiba roja"), formerly classified, as *Bombacopsis quinata* is locally known as ceiba roja, cedro espino, pochote, saqui-saqui and tolúa. It is a dry zone deciduous species, and its natural distribution can roughly be divided into three regions. The northern zone includes Honduras, Nicaragua and Costa Rica, the central zone includes Panama and the departments of Atlántico, Antioquía, Bolívar, Cesar, Córdoba, Sucre and Magdalena in Colombia, and the eastern zone comprises the department of Arauca in Colombia, and much of low-elevation western and central Venezuela (Kane et al., 1993). *Pachira quinata* occurs at elevations from sea level to 900 m in areas where annual rainfall ranges from 800 mm (north of Colombia) to 3000 mm (Cabo Blanco, Costa Rica) and a strong, well defined dry season of 2-6 months characterises its natural range (Kane et al., 1993). It grows on a variety of sites. It can occur on well-drained upland soils as well on imperfecttly drained Vertisols on low flatland sites (Donahue and Gutiérrez, 1991).

P. quinata has many uses, its wood is highly prized for use in construction and the manufacture of crude furniture. Because it is easy to propagate vegetatively, it is used as living fence posts and is planted for shade for cattle. Demand for its wood has led to over-explotation in most areas of its geographic range. Populations of this species are most threatened in the Choluteca Valley, Honduras (Dvorack and Donahue, 1991), in some areas of eastern Nicaragua (Donahue and Gutierrez, 1991) and in North of Colombia and although there is a considerably inventory in Venezuela, it is now being exploited heavily (Kane at al., 1993).

h) *Swietinia macrophylla* (local name caoba), it is naturally distributed from Southern Mexico, Southward to Colombia, Venezuela, and parts of the upper Amazon and its tributaries in Peru, Bolivia and Brazil. It is a tree of more than 40 m and 2 m in diameter above the heavy buttresses; boles are clear from 18-24 m. Its leaves are pinnately compound, ovate-lanceolate. Its fruit is a large (4-6") greenish-brown woody capsule, splitting into 5 parts releasing flat, long winged, light-brown seeds. The wood is dense, close-grained and red-brown. It is easy to work with hand or machine tools. It is easy to finish and takes an excellent polish slices on rotary cuts into fine veneer. It is uses in high-class furniture, cabinet making, panelling musical instruments, boat interiors, pianos and carving (http://www2.fpl.fs.fed.us; http://tropilab.com/mahogany.htlm). It is one of the most economically important tree species that grows in Latin America (Morris et al., 2000), and fears have arisen amongst many scientists that its population thought Central and South America are in danger of possible extinction (Roozen, 1998).

i) *Tabebuia rosea* (local name roble,) native of tropical America. It is a tree, which grows up to 25 m high and 70 cm of diameter (Borcher and Tomlinson, 1984). The opposed leaves are palmatilobate with five coriaceous dark green leaflets. The flowers are in clusters, pink to lilac, with a heart turning from yellow to white. The fruits are elongated cylindrical capsules full of flat winged seed. Its very hard wood stands wood mushrooms and is used to make wheels and crosspieces (Borcher and Honda, 1984).

Appendix 6.1. Mean value of nitrogen content of herbaceous vegetation, shrub and arboreal species in multistrata silvopastoral systems with different levels of structural complexity.

Species	Pasture	Past+Shrubs	Past+Arb	Past+Shr+Arb	Past+Shr+Arb+Tim
Dichanthium aristatum	12	12	13	14	12
Brachiaria mutica	17	18	18	18	17
Centrosema pubescens	33	33	32	31	33
Desmodium uncinatum	26	28	26	25	29
Rynchosis minima	25	26	26	26	28
Teramnus uncinatus	30	30	29	28	32
Vigna sp	31	31	32	33	32