NINA Report 570

Silvopastures in Central America

PACA – Final report

Graciela M. Rusch
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Mariel Aguilar-Støen
Christina Skarpe
Muhammad Ibrahim

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Norwegian Institute for Nature Research

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Abstract

Rusch, G. M., Pezo, D., Aguilar-Støen, M., Skarpe, C. & Ibrahim, M. 2010. Silvopastures in Central America: PACA – Final report. – NINA Report 570. 50 pp.

Silvopastoralism constitutes the predominant feature of the livestock production landscapes in Central America. It consists of an agroforestry practice that integrates trees with forage and livestock production. The dominant landscape features is a matrix of pastureland with dispersed trees and other tree formations. The principal objective of “Silvopastures in Central America” (PACA) was to build capacity about the management of diverse forage resources in the region with the ultimate aim to improve the management of the silvopastoral system and reduce pasture degradation. For this purpose the body of the research consisted in the work of 9 MSc and 2 PhD students, with scientists at the three partner organisations participating in various collaborations in the supervision of the theses work. An important contribution of PACA was a better understanding of the semi-natural pasturelands in the sivopastoral system, both from an ecological and socio-economic perspective. These pasturelands had earlier received limited attention in spite of constituting the basis of the livestock production in the region. Burning is a common practice in some areas. The social and socio-economic studies showed that the way the practice is used is determined by the kind of agro-pastoral activity, i.e. cropping, livestock production in medium-sized farms, and in large farms on savannah, and that depending on these differences there are various opportunities to reduce harmful effects of the land use. The studies also illustrate the complexity of the socio-economic system that determines the choices and usages of trees in silvopastoral systems, using Petén as a case study. The research revealed that the levels of adoption of silvopastoral systems and the benefits harvested are variable and that there is a considerable potential for further adoption and profitability of silvopastoralism. The ecological studies examined various aspects of the tree-cattle-pasture system. Findings show that the semi-natural pasturelands are diverse plant communities and generally dominated by native grass species. Tree regeneration in pastures is common, but establishment of trees is limited by grazing and other practices aimed at maintaining the herbaceous cover. Productivity of semi-natural and cultivated pasturelands did not differ, in both types of pasturelands productivity corresponded to the amount and the distribution of rainfall. The semi-natural pastureland had a more stable seasonal productivity. Under trees, pastureland productivity generally declines, but there is a trend that the attributes of the tree such as evergreen or deciduous foliage, can determine the outcome of the effect. Cattle activity tracks paddock heterogeneity. Open areas are more used for feeding and areas close or under the trees, for resting. In large and heterogeneous paddocks cattle select certain foraging patches and avoid others, and within the patch, some species are selected more than expected by random, but most plant species are consumed according to their abundance. In the dry season, cattle selected more shrubs and tree parts than in the wet season.

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Sammendrag

Rusch, G. M., Pezo, Danilo, Støen, M. A., Skarpe, C. & Ibrahim, M. 2010. Skogbeiter i Mellom-Amerika: PACA – Sluttrapport. – NINA Rapport 570. 50 s.

Skogbeitebruk (silvopastoralisme) er en dominerende form for kjøtt- og melkeproduksjon i Mellom-Amerika. Denne landbrukspraksisen integrerer skogbruk og beite for storfe. Landskapet er formet som en mosaikk av beitemarker med innslag av spredte trær og treklynger. PACAs viktigste mål har vært å bygge opp kompetanse om forvaltningen av de ulike beiteressursene i regionen for å kunne forbedre forvaltningen og hindre at beitemarkene forringes. Prosjektet har vært bygd opp rundt 9 MSc- og 2 PhD-oppgaver. Forskere fra de tre samarbeidsorganisasjonene har deltatt som veiledere. I løpet av prosjektperioden harPACA bidratt til å bedre kunnskapen om semi-naturlige beitemarker både fra et økologisk og et sosioøkonomisk synspunkt. Trass i at disse beitemarkene utgjør mesteparten av beiteressursene i regionen, har de tidligere fått liten oppmerksomhet. Brenning er vanlig praksis i visse områder. De sosiale og sosioøkonomiske studiene viser at brenningen er avhengig av typen jordbruksaktivitet, og at det således er ulike muligheter for å redusere skadelige effekter. Studiene illustrerer også kompleksiteten i det sosioøkonomiske systemet som avgjør valg av trær og skogbrukspraksis, her illustrert med Petén som studieområde. Prosjektet har vist at det er mulig å øke lønnsomheten og omfanget av skogbeitebruken i området. De økologiske studiene omfattet flere aspekter ved systemer med trær, buskap og beitemark. Resultatene viser at semi-naturlige beitemarker er mangfoldige og generelt dominert av lokale grasarter. Foryngning av trær i beitemarker er vanlig, men etablering er begrenset av beitet og andre tiltak som gjøres for å opprettholde beitekvaliteten. Produktiviteten er like høy i semi-naturlige som i kultiverte beitemarker. I begge typene er produktiviteen påvirket av både mengde og fordelingen av nedbør, men de semi-naturlige beitemarkene har en mer stabil sesongproduksjon. Beiteproduksjonen er generelt lavere under trær, men ulike tretyper (løvfellende og ikke løvfellende) har ulike effekter. Buskapens arealbruk speiles av heterogeniteten i beitemarkene. Dyrene beiter mest i de åpne arealene og bruker de skyggefulle områdene under og nære trær for å hvile. I store og heterogene innhegninger velger de ut visse beitefelter og unnviker andre. Innem et beitefelt er det noen arter som prefereres, mens de fleste arter konsumeres i forhold til deres mengde. I tørkesesongen beites mer busker og annet forvedet materiale enn i regntiden.

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Contents

Foreword

The “Silvopastures in Central America – PACA” project crystallized the first formal collaboration among the Norwegian Institute for Nature Research (NINA), the Center for Tropical Agriculture Research and Education (CATIE) and the Center for Development and Environment (SUM, University of Oslo). The collaboration has been centred around a common interest: to improve the understanding of the silvopastoral system in seasonally dry areas in Central America. The questions asked cover a wide span of themes and illustrate the complexity of socio-ecological systems, and the many factors that need to be taken into account in order to improve livelihoods and to sustain a long-term and productive utilisation of the resource. The results of the research are summarised in the chapters of this report. They show the variety of disciplines, methodological approaches, spatial and temporal resolution, and level of biological and organizational hierarchies dealt with in the studies.

The achievements we summarise in this report would not have been possible without many contributions of various kinds. We are thankful to Norad, whose funding was instrumental to establish this collaboration, and to Odd Terje Sandlund at NINA and John Beer at CATIE who forged the linkage between the organisations. The body of the field data has been collected by a large number of young scientists in Latin America and Norway, whose work is only partly acknowledged in this report. Thanks to Maria Aastum, Bente Anfinnsen, Patricia Colón, Jimena Esquivel, Harold Gamboa, Hallvard Holtung, Anders Nilsen, Sonia Ospina, Lester Rocha and Raúl Velásquez for their enthusiasm and dedication. During the course of the project, the initial research group eventually expanded including a larger of number scientists, research disciplines and organisations. Thank you to the colleagues at the Norwegian University of Life Sciences (UMB), Stein R. Moe and Arild Vatn; at the Norwegian University of Science and Technology (NTNU), Bård Pedersen and Håkan Hytteborn; at the University of Bangor, Wales, Fergus Sinclair; and at CATIE, Tamara Benjamin, Fernando Casanoves, Fabrice DeClerck, Bryan Finegan, Celia Harvey, Andreas Nieuwenhyse and Jairo Mora. The CATIE-NORAD project personnel at the offices in Muy Muy and Flores were of enormous help and ultimately made the field data collection possible. Thanks to Amilcar Aguilar, Maricel Piniero, Jorge Ruíz and the field- and office-assistance personnel for their friendliness, hospitality and helpfulness.

March 28th 2010
Graciela M. Rusch

1 Introduction

Silvopastoralism constitutes the predominant feature of the livestock production landscapes in Central America. The landscape derives from the clearing of tropical forest and consists of a dominant matrix of pastureland with dispersed trees and other tree formations such as live fences, secondary forests and riparian vegetation (Sauceda 2010).

Pasture degradation has been defined as “the negative change in pasture condition, associated with negative ecological and environmental changes, or simply as a decrease in pasture quality leading to a reduction in animal productivity. Degradation can be a reduction in vegetational cover or soil fertility, the loss of desirable or the invasion of undesirable species” (Szott, Ibrahim & Beer 2000 p16). Low pasture productivity and deforestation are serious problems in Central America.

The main objective of the PACA-project was to build regional capacity in Central America about managing diverse forage resources with the ultimate aim to enhance cattle production and reduce pasture degradation (CATIE-NORUEGA 2009). Perhaps one of most important contributions of the research has been the focus on the semi-natural pasturelands in good condition. Despite being the basal resource for the milk and meat production in the region, knowledge about these pasturelands has been practically inexistent. There was little knowledge about the components of the herbaceous flora, of the spatial variability of states and conditions of the grasslands and about the causes of that variation, and about fundamental properties such as their diversity, their productivity and how these grasslands are used by cattle. In the region, there is obviously a need for intensification of the production and to improve farm production sustainably. But there are still considerable challenges to identify which are the bottlenecks and the development paths that can fulfil these needs. The challenge of identifying sustainable pathways of development is a guiding objective, i.e. how to improve production and welfare without causing unwanted bi-effects which can compromise long term benefits. PACA evaluated some interventions that are commonly recommended or adopted, such as the introduction of certain improved forage plant varieties. The results indicate that in the area of the study, there are no clear benefits of replacing grasslands in good condition with these varieties. Further, natural grasslands appear to be functionally more stable throughout the year with the same annual yield. The indiscriminate replacement of natural grassland by improved varieties appears to be unjustified if no consideration is given to habitat differences and to the particular management conditions that lead to higher yields. A massive replacement of the natural pasturelands in the region would be an ecologically and economically high-risk enterprise. It would erode the source of variability that confers adaptation to the shifts in space and time of the biophysical environment. In view of the predicted changes in the climate of the region due to global warming the maintenance of a wide and diverse resource base appears to be a wise way to reduce risk and vulnerability.

This report summarizes the achievements of the PACA project, CAM-2012 CAM-03/003 Research collaboration between NINA, SUM and CATIE. The body of the research consisted in the work of 9 MSc and 2 PhD students, with researchers at the three partner organisations participating in the supervision of the theses and dissertation work in various collaborations. The research network was expanded with the participation of students from Norwegian universities (UMB and NTNU) and with the enrolment of the PhD students at NTNU and in CATIE’s sandwich program with the University of Bangor, respectively. The students and researchers involved co-authored the publications listed in the Appendix I.

The report is organised as a series of chapters which summarize the main achievements of the project (Chapter 2) and present extracts from the MSc and PhD theses (Chapters 3 – 11). Chapter 2 highlights the key role that the support from Norad has had in setting the foundation for the partnership among the organisations, based on common research interests, with a view about the importance of a wide knowledge base to direct development measures, and on a commitment to build the research capacity in the region. We summarize in numbers the products of the project.

Chapters 3-11 show some of the main results of the individual studies addressing a variety of questions of the socio-ecological silvopastoral systems in Central America. The studies show a wide range of questions, methodologies, approaches and scales and highlight the diversity of issues that forms part of the decision making framework for the management of the natural resources on which the silvopastoral systems in the region rely on. Chapter 3 describes the areas where the studies have been conducted in Guatemala and Nicaragua.

The questions about the social and socio-economic system underlying decision making at the farm level are raised in Chapters 4 and 5. Chapter 4 presents an analysis of the various social, historical and socio-economic factors that the decisions about the use of fire and management of burnings in Petén, Guatemala. It shows the critical role that the kind of agro-pastoral activity, linked to the size of the farms, has in determining the use of the practice. In small farms, the main reason for burning is the low cost of the practice in terms of money and effort for preparing the land for cultivation of crops. Medium size farmers, use fire to manage pastures, primarily to remove low quality forage due to the overproduction in the rainy season. They argue that better capacity to manage the seasonality of the grass production would minimize the need of burning. Chapter 5 illustrates the complexity of the socio-economic system that determines the choices and usages of trees in silvopastoral systems, using Petén as a case study. The research revealed that the levels of implementation of silvopastoral systems and the benefits harvested are variable and that the potential for further implementation is great for all farmers. Compared to the potential of intensification and diversification that silvopastoral systems may have, there is still a great unfulfilled potential of optimising the economic, social and environmental benefits attained in the region. One clear trend shown in the study is that in the present situation of silvopastoral implementation few farmers commercialize products from the trees on their farmland. The production of tree-products is almost exclusively aimed at own consumption or for products to supplement the own the cattle production.

Chapters 6-11 deal with ecological aspects of the tree-cattle-pasture system in the area of Matagalpa, central Nicaragua, and analyse properties and responses of the components and the interactions among them. Chapter 6 presents a characterization of the pasturelands in the silvopastoral systems. Currently, most of the livestock production in the area is based on the use of semi-natural vegetation but there has been limited knowledge of their composition and of the factors that affect it. The studies have shown that the vegetation is composed of a large number of species, the majority of them native to the area, and with predominance (ca 45% of the occurrences) of four species of native grasses and one forb. They also show that there is a correspondence between the management of the paddocks and the plant community composition of the grasslands. Annual and short-lived species, which are generally associated to highly disturbed habitats (for example through overgrazing) characterised some of the large paddocks that are used primarily by dry cows. Unanswered questions incude: which are the management and grazing regimes that have maintained grasslands with good cover of perennial native grasses, and which are the management factors that have led to low vegetation cover and higher cover of forbs of little forage value. Chapter 6 also deals with the composition of trees in the silvopastoral system and their potential for natural regeneration. The results show that a good number of species, with the capacity to regenerate in openings (early colonizers or pioneer species) have a high potential to recruit in paddocks in the current silvopastoral landscape, but that establishment is limited by weeding and by grazing. Several species with high commercial value, for example for timber, are among these species. Regeneration is more limited for species that regenerate under tree cover (secondary species) and there are several factors that could potentially limit recruitment, namely seed production, dispersal and the availability of favourable micro-sites for germination and seedling establishment.

Chapters 7 and 8 deal with the functioning of pasturelands and of pastureland species. Chapter 7 deals with responses to rainfall seasonality, a key aspect in the light of the changes in the amount of rainfall that have been predicted for the region due to global warming. The findings show that, in the area, pastureland productivity responded positively to the amount of rainfall, but neither sown pastures nor grasslands responded positively to events of high amounts of rainfall, likely due to high rain run-off and low infiltration in these occasions. Pastureland productivity was not only affected by the amount but also by the distribution of rainfall, and there was a trend that the sown pasture was more sensitive to the spacing of rainfall events than the grassland. In the area, and without any additional supply of water and nutrients, sown pastures and semi-natural grasslands have similar annual productivity, but sown pastures have a more defined peak of production in the rainy season, and appear to produce more biomass per unit rainfall, but semi-natural grasslands have a more stable production through the seasons and are more productive at the end of the rain season. Chapter 8 addresses the question of how pastureland species respond to grazing (clipping), drought and nutrient supply and which attributes of the species determine such responses. The results show that water is the major limiting factor for growth in two common grass species. Both species recover their tissues after clipping, but the species from fertile habitats restored the loss more rapidly. Variability in the responses to drought and clipping between populations of the same species growing in fertile and infertile habitats were also detected.

Chapters 9, 10 and 11 deal with three kinds of competitive/facilitative and trophic interactions: between trees and grassland species, between cattle and trees, and between cattle and grassland. Chapter 9 reports about the negative effects of two species of trees, with different pattern of leaf fall, on the productivity of the grassland. In both cases there was a reduction of production under the tree compared to the open grassland, but it appears that the reduction is larger under the tree species that seasonally shed leaves. In Chapter 10 the question of how cattle use the trees in the paddocks is addressed. The findings indicate that cattle rested closer to trees and fed further away from trees than expected by random, and that there were different resting and feeding distances associated with different tree species. Both resting and feeding were performed closer to small trees than trees of medium and large size. Cattle rested closer to trees at midday than in the morning and afternoon and they fed closer to trees in the morning and at midday than in the afternoon. Finally, Chapter 11 addresses the question of grassland patch and plant species selectivity by the cattle. In paddocks of low soil fertility, cows grazed selectively at two spatial scales, they selected particular patches within the paddock and grazed more on certain grassland species. However, it appears that other factors than dietary preferences affected the choice of feeding sites, and grazing on a particular species was associated to its abundance. Choices were also related to the size of the plants. Cattle preferred relatively short vegetation in their feeding sites, whereas sites with taller species such as shrubs and vines were avoided. In contrast, some of these shrubs and vines were selected in the diet. Also, selectivity indices for some shrubs and trees increased during the dry season.
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2 Project achievements and outputs

The achievements from this project comprise three areas: the production of knowledge, capacity building, which included training of young researchers from Central America and Norway, and networking.

The project has produced 9 MSc theses and two PhD theses (one under completion at the time of the preparation of this report, expected defence in July 2010). Of the 9 MSc students, five were women (2 Norwegians and 3 Latin Americans) and four were men (2 Norwegians and 2 Latin Americans). The three senior researchers from Norway involved in the project are women. In light of the goals that were stated at the start of the project regarding gender balance, the project has achieved an even recruitment of students (See appendix I and table below).

PACA had the aim to support 6 MSc and 1 PhD student from the local region, and this aim has been achieved. The PhD candidate enrolled in a sandwich PhD program between CATIE and Bangor University, Wales, UK (UBW). We applied for a Quota stipend to support another PhD student. Lester Rocha succeeded in obtaining a Quota program scholarship at NTNU. A summary table of the theses and dissertations is presented below.

Name	Thesis	Institution	Country	Gender	Year	Funding source
S. Ospina	MSc	CATIE	Colombia	F	2005	PACA
J. Esquivel	MSc	CATIE	Colombia	F	2005	PACA
P Colón	MSc	CATIE	Honduras	F	2005	PACA
R Velásquez	MSc	CATIE	Colombia	M	2005	PACA
B Anfinnsen	MSc	UMB	Norway	F	2005	UMB –own
M Aastum	MSc	NTNU	Norway	F	2006	NTNU-own
A Nilsen	MSc	UMB	Norway	M	2006	UMB – own
H Holtung	MSc	NTNU	Norway	M	2008	NTNU-own
H Gamboa	MSc	CATIE	Colombia	M	2009	PACA
L Rocha	PhD	NTNU	Nicaragua	M	2009	Quota program
S Ospina	PhD	CATIE-UBW	Colombia	F	2010	PACA

Capacity building

PACA made an important contribution to expand the capacity of local counterparts on research methods. The project organised a training workshop on socio-economical research methods with participants form the region. More generally, the joint work with the students enabled a fruitful exchange of approaches and methods among PACA participants. PACA's work was linked to the CATIE-NORUEGA (2009) project, and the results of research were communicated through different channels. The research was discussed and followed closely by the technical personnel of the project, both regarding methods and theoretical approaches. Some results were included in participatory learning sessions held with the farmers at the end of the CATIE-NORUEGA project.

Both the Norwegian and Central American partners understoodthe importance of the participation of Norwegian students in the cooperation. It is a pre-requisite to develop interest and to build up the capacity on the region in Norway, essential for any kind of international work in the region. However, an organised scheme to promote the interest and the capacity of Norwegian students and young researchers in this part of the world is lacking. The project has supported Norwegian students with supervision time and facilitating the field work in the region (Nicaragua and Guatemala). PACA provided the Norwegian students with lodging (space in the Degraded Pastures project house and field laboratory), field assistants, transportation in the field, and other kinds of local support. The project has been a platform for Norwegian students to gain experience about the region and in particularly with a tropical cultural landscape supporting silvopastoralism.

Research results and publications

The research conducted in the project has contributed to the understanding of the properties and functions of seasonally dry silvopastoral ecosystems in Central Nicaragua and Guatemala. Through this research we have specifically gained knowledge about i) how trees and cattle, and cattle and pastures interact in these systems, ii) the differences and similarity in ecological functions between semi-natural grasslands and sown pastures, iii) how dominant grass species in silvopastoral pastures (native and exotic) respond to drought, nutrient supply and grazing, iv) the potential of the natural recruitment of trees in paddocks under silvopastoral management, and which are the drivers and motivations that determine v) practices with important ecological effects (fire) and vi) the use and choice of tree species by farmers in these systems. Research results have been published as thirteen articles in peer-reviewed journals. Additionally seven articles from the PhD theses have been submitted or are under an advanced stage of preparation (see list of theses and publications in Appendix I). Based on the ranking of the journals/publishers made by the Norwegian Database for Statistics on Higher Education (DSH), the project produced 16 academic points. Considering this figure in light of the person/year work financed by Norad the project scores high in terms of average productivity per researcher (2.1 points/year/researcher).

Other forms of dissemination of the project results were: i) A seminar about methods to study local knowledge (regional, at CATIE), ii) A workshop with participants from the region presenting the core of the research results by 2006 (regional, at CATIE) and participation in three international conferences: IV Latin American Congress of Agroforestry for Sustainable Animal Production, October 2006, Varadero, Cuba; International Symposium on Silvopastoral Systems, November 2008, Venezuela and the II World Congress of Agroforestry, August 2009, Nairobi, Kenya.

Consolidation of cooperation Norwegian – CA research institutions

The project served to consolidate a partnership among CATIE, NINA and SUM. Overcoming the challenges at the initial phases of the project, common at the start of collaboration, such as differences in scientific backgrounds and approaches, have built up trust and strengthened the cooperation.

Through the support to Norwegian students, the project consortium was expanded, adding the cooperation with research groups at the Norwegian University of Science and Technology (NTNU) and the Norwegian University of Life Sciences (UMB). The project was conducted in collaboration with the project "*Multistakeholder Participatory Development of Sustainable Land Use in Degraded Pasture lands in Central America*" (supported by the Norwegian Government), coordinated by CATIE. This gave us an excellent opportunity to contribute with research to an ongoing development progamme.

Sustainability of the cooperation

The funding received from Norad to support institutional cooperation was instrumental in providing the opportunity to NINA, SUM and CATIE to initiate cooperation. The project has helped to establish, strengthen and expand the partnership through the acquisition of research funds from other sources and networking with other partners from Norway, Europe and other regions in Latin America. Given that the project was successful in terms of research production and that contacts with CATIE were strong, the PACA project worked as a platform for the formulation and implementation of further applied research. As a result, participants in the project (CATIE, SUM and NINA) together with new partners (listed below) are currently involved in four new research projects (two financed by the Research Council of Norway and two by the 7th Frame Programme, European Union).

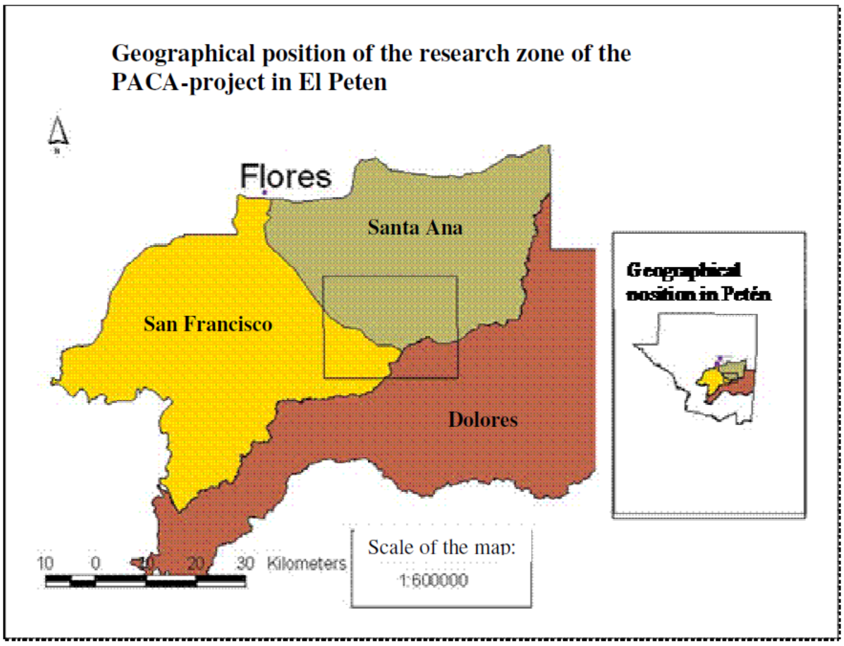
Partner	Project	Funding source
University of Life Sciences (Norway)	SILPAS	RCN
Centro Tecnológico Forestal de Catalunia (Spain)	SILPAS	RCN
Høyskole i Hedmark (Norway)	SILPAS / MF-Landscapes	RCN
Consejo Superior de Investigacio-nes Científicas (Spain)	MF-Landscapes / FUNCiTREE	RNC – 7FP
CIRAD (France)	FUNCiTREE	7FP
University of Wageningen (Nether-lands)	FUNCiTREE	7FP
6 addtional partners from Europe (5) and Latin America (2)	POLICYMIX	7FP

3 Description of the study areas

The activities in the project have been conducted in two main geographical areas, El Petén, Guatemala and Muy Muy, Matagalpa, Nicaragua. Below follows a description of the two areas.

Petén

Petén, Guatemala is located in the northern part of the country.
The natural ecosystem type in the region is humid tropical forest (CATIE-NORUEGA 2009). During the year there is one long rainy season and a dry season of varying duration in the period of December to May (INSIVUMEH 2000, in Annfinnsen 2006)). The average annual rainfall is 1796 mm and the average temperature 26° C (CATIE-NORUEGA 2009). Between-year variation in rainfall is also relatively large.



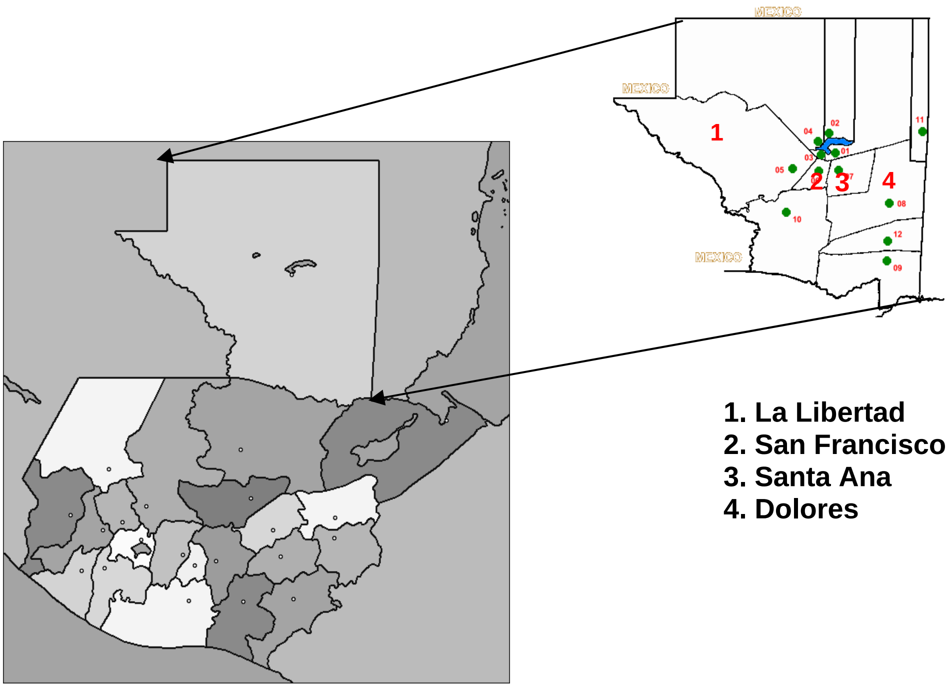
Source: García, CATIE-Norad 2005 in B. Anfinnsen 2006.

From the Spanish conquest in 1697 until the middle of the 1960s, El Petén was sparsely populated and about 90% of the area was covered with forest. From the 1890s to the middle of the 1960s, the most important economic activity of the region was traditional, small-scale production of maize and the harvest of forest products, especially rubber, for exportation (Anfinnsen 2006). During the last 40 years of the last century, 42% of the forest of Petén was converted to agricultural land and pasture (INE 2001). At present, Petén is the most important area for livestock production in Guatemala. However, few efforts have been made to work with the cattle farmers to make their production methods more sustainable and productive, possibly in part due to the fear for being perceived as “endorsing a practice that is widely considered ecologically inappropriate” (Rice & Greenberg 2004 p454, cited in Anfinnsen 2006).

Municipality Characteristic	**Santa Ana**	**Dolores**	**San Francisco**	**La Libertad**
Area (km^2)	1.008	3.050	320	7.047
Altitude (m asl)	135	436.5	230	190
Population (2002)	14.602	32.404	8.917	67.252
% Poverty	64	65	56	68
% Illiterate	28	23	18	20

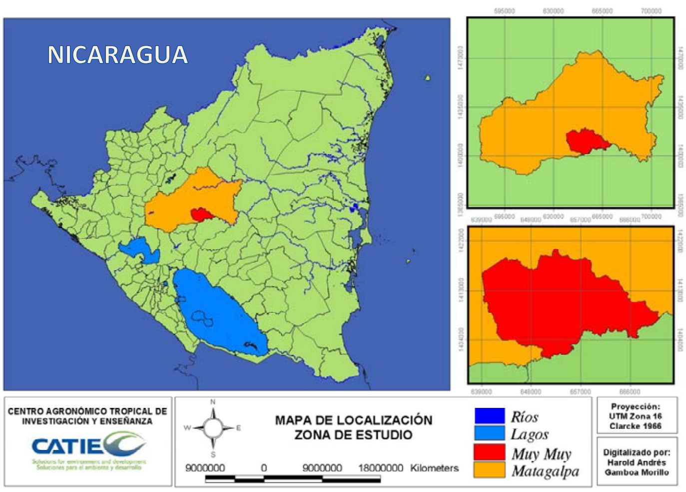
Source: XI Censo de población y VI de vivienda. INE 2003, and Oficina Regional de planificación 2003 *in* Colón 2005.

The PACA study area described in Chapter 5 was situated near El Chal Dolores, Guatemala with a population of approx. 3800 inhabitants, an extension of 200 km2 (Anfinnsen 2006). The study in Chapter 4 was conducted in four of the twelve municipalities in El Petén: San Francisco, La Libertad, Santa Ana and Dolores, the first two municipalities, with a predominant savannah landscape (Colón 2005)



Muy Muy, Nicaragua

The studies in Nicaragua were conducted in the watershed of the Río Grande de Matagalpa, in central Nicaragua. The area is located in the municipality of Muy Muy, one of the pilot areas of the project " *Multistakeholder Participatory Development of Sustainable Land Use in Degraded Pasture lands in Central America* - CATIE-NORAD". The predominant land-use form is livestock farming with relatively homogeneous livestock management systems.



Area of the studies conducted in Nicaragua. Municipality of Muy Muy, County of Matagalpa. Source: Gamboa 2009

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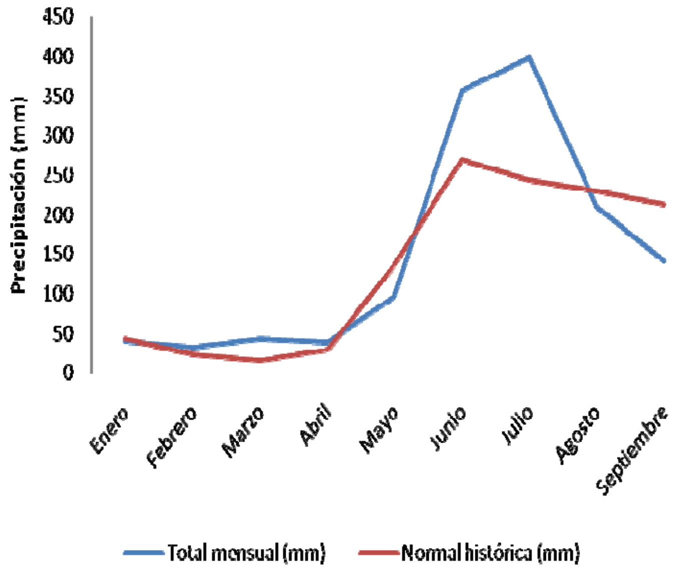
The natural vegetation of the region corresponds to a transitional tropical sub-humid forest (Holdridge, 2000) with semi-deciduous vegetation, and referred in Bullock *et al.* (1995) as seasonally dry tropical forest. The pastureland vegetation in the study is an assemblage of native and naturalized species including grasses, herbs and woody plants. The landscape is shaped by silvopastoral activities, typically consisting of various elements, of which pasturelands with dispersed trees predominate but also of live fences and secondary forests and forest successions in various stages of development.

In the region there is a clear contrast between the rainy and dry periods. Rainfall recorded between November/December to April/May is usually less than 10% of the annual mean (1500 mm). The annual average air temperature is 24°C. The topography is undulating, with slopes between 5 and 45%.



Seasonal rainfall distribution. Historic normal (red line) and monthly totals in 2008 (in blue line). Source: Gamboa 2009

4 Local knowledge on fire management in silvopastoral systems in Petén, Guatemala

This chapter is an extract from the thesis by Patricia Colón.

Burning is a common practice for clearing and weeding of pastures in silvopastoral systems in Central America. If not adequately controlled, it is a source of damage to secondary forest and woodland remnants and crops. Burning used to manage agro-pastoral land, has increased the risk of fires in Guatemala, during the period 1998-2003 fires have affected an area of 29 780 ha. Despite the severe consequences of fires for the remaining forest cover, biodiversity and the global carbon cycle, bans on burns give rise to controversy since the practice has a long history of use in the region. Regulations about frequency and timing of the burning are likely to be a more successful strategy to prevent damage.

Farmers have locally specific knowledge about various practices of burning which needs to be documented and incorporated in any regulation scheme to ensure acceptability and success in its implementation. The investigation aimed to understand the rationale and context in which livestock farmers in El Petén use burns, as well as the factors that affect their decisions about the practice.

Specific objectives were:

- To characterise the livestock farmers in the Petén area
- To describe the practice of burning in the area
- To explain the management context of the use of fire in terms of the properties of the pastures.
- To identify fire tolerant plant species according to the farmers' perceptions.
- To describe farmers' perceptions of the benefits and drawbacks of burning.

Background

To address the question about burning, it is necessary to understand the context in which the practices are used. In Petén there are four types of land-tenure: Municipal land with usage right, Farmers' cooperatives, Private land and various forms of informal tenure: rented, borrowed, informal ownership (Jaramillo and Kelly 2001). The following statistics describes the situation of occupancy in 1989: 581 382 ha were privately owned by 4 593 farmers. Approximately 30 000 farmers were in the process of acquiring land ownership titles and most of the remaining 638 618 ha were occupied by farmers lacking tenure rights.

The area in Guatemala dedicated to husbandry and the number of cattle heads in the early 1990's approximately doubled values in 1950 (Kaimowitz 1996)

Year	1950	1970	1978	1983	1991
Area with pasture (millon ha)	0.8	1.0	1.1	1.3	1.4
Cattle heads (millon)	1.0	1.5	2.1	N.d.	2.2

Use of fire as agro-pastoral practice

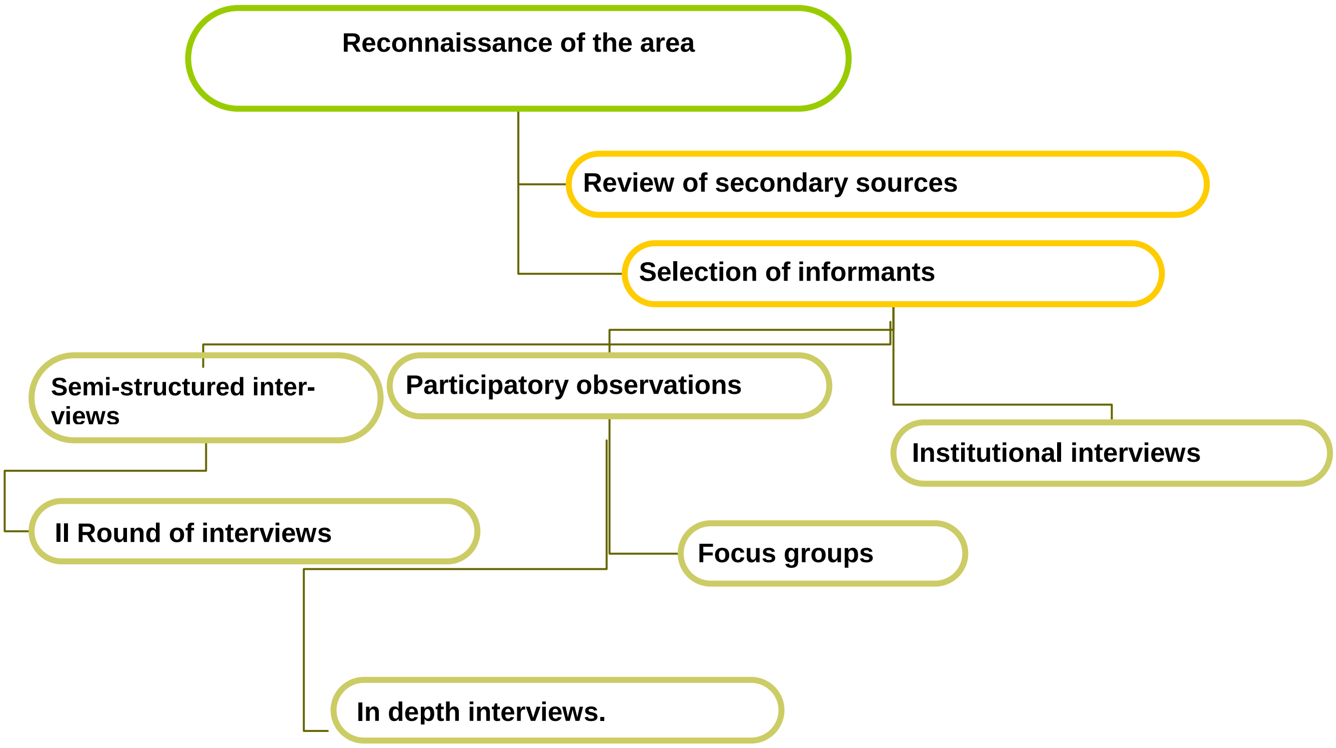
Fire is a widespread practice in agro-pastoral systems globally, aimed to various purposes, i.e. remove old plant material from pastures, with low palatability, to promote re-sprouting of forage plants and higher nutritious value, to control of insect attacks, pathogens and parasites, to hinder the establishment of weeds, to establish fire-breaks (Gutiérrez 1996, Rodríguez 2004) and to maintain a balance between tree and pasture cover (LEAD Virtual Center 2004).

Repeated burns reduce the amount of organic carbon that enters the soil and can lead in the long term to losses of fertility (LEAD Virtual Center 2004). The losses of organic matter can in turn result in lower rainfall infiltration rates into the soil, higher surface rainfall run-off and finally loss of water available for the vegetation. The effects on the vegetation depend on the timing (burning season), the temperature that the fire develops and the physiological status of the plant (Martínez 1983, in Colón 2005). Several studies show an increase in the content of protein, P, K and Ca in plant tissues that re-sprout after burning. In areas where the natural vegetation is forest, fires contribute to maintaining the cover of the herbaceous vegetation.

The relevance of the local knowledge
Since the 1980's there has been an increasing interest on studies about local knowledge systems in relation to the use and management of natural resources. This view has radically changed the development paradigms, from a view of farmers as mere recipients of knowledge to that in which local experiences and knowledge are incorporated in models of local development. This change is mainly due because of the large differences between the perceptions of planners and the local communities about the causes and the solutions to environmental and natural resource management challenges (Lubbock 1998, Turner *et al.* 2000, in Colón 2005). Understanding of local perceptions is a pre-requisite to the success of any development program.

The local knowledge is dynamic and it spreads among populations due to movements or migration, creating a fusion between the original knowledge and the knowledge acquired in the new context. In agro-pastoralism, the new forms of knowledge have a bearing on decision making and the management of productive systems (Valverde *et al.* 1997, in Colón 2005). This aspect needs to be taken particularly into account in Petén, Guatemala where during three decades the area has been converted in the main destination of low income farmers from all over the country, driven by the lack of land and by poverty, the hope of owning land and migration due to war. According to SEGEPLAN (1992), this diversity of origins has caused more degradation of the resources than in other areas, due to the lack of knowledge about the ecosystems.

Methodological approach – Phases of the investigation
The study was conducted in three phases. The first phase consisted of a review of secondary sources in order to design the field work, the second was the collection of data in the field and the third phase consisted of data analyses. The sequence is shown in the diagram below:

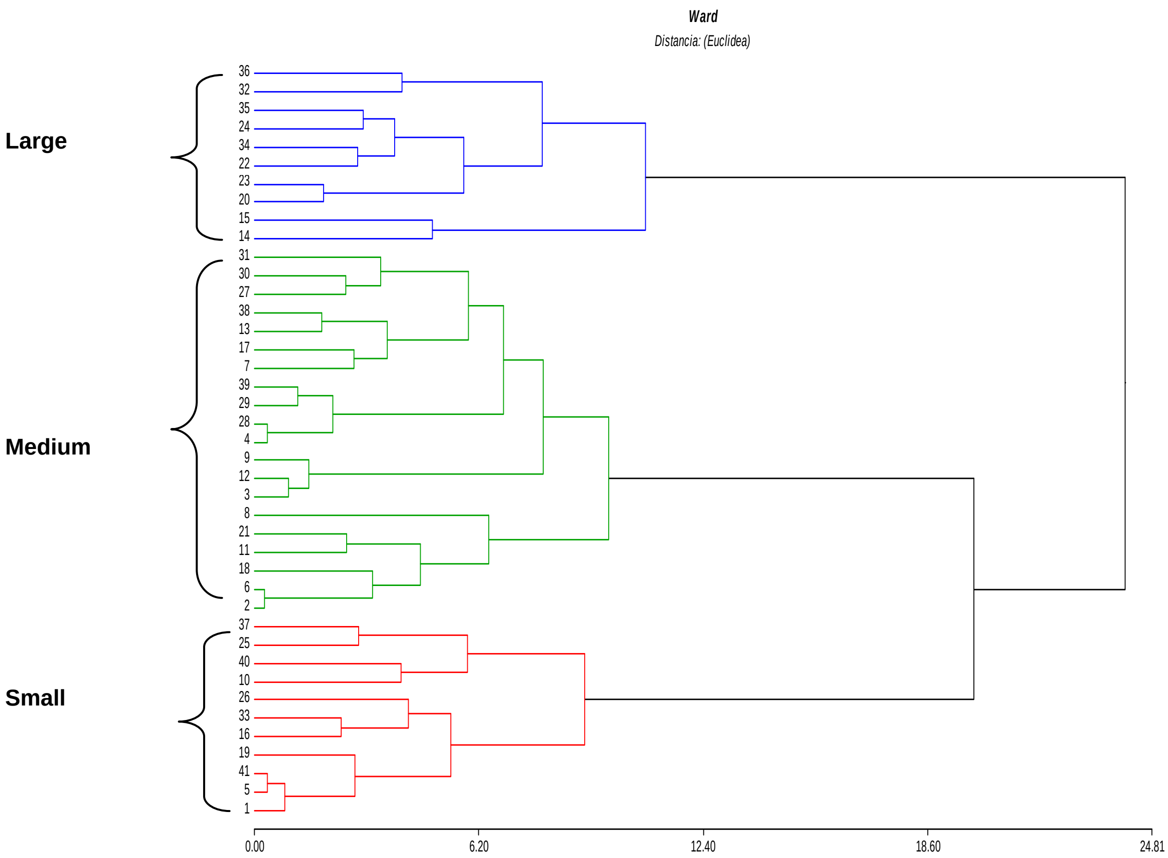


A series of variables that can affect the knowledge and the local practices were taken into account to stratify the interviews and in the analyses, namely: land form, size of the farm, education, the time and experience of the farmer in the area, land tenure type, organisational level, and attitude of the farmer (tendency to take risks). It is assumed that longer experience of the farmer in the area, higher the education and higher influence of organisations in the area would lead to more knowledge about the practice of burning. It was also assumed that there would be differences in the way the practice is used depending on the land form, and that larger farmers would have more options to avoid the negative impacts.

Results and discussion

The livestock farmers in the area were characterised according to the size of the farm. This separation was considered important to analyse decision according to livelihood patterns, which was the underlying model for this investigation.

Characteristic	**nr**	**Age p = 0.05**	**Farm size (ha) p = 0.05**	**Nr of livestock p = 0.05**	**Distance to tarmac road (km) p = 0.05**
Group					
Small	11	49 ± 11.7[a]	80.3 ± 139.3[b][1]	46.36 ± 31.3[b]	3.73 ± 3.26[b]
Medium	20	56 ± 9.55[a]	153.5 ± 113.95[b]	124.8 ± 82.96[b]	12 ± 8[a]
Large	10	50 ± 9.88[a]	654.9 ± 290.1[a]	456.6 ± 351.12[a]	4.40 ± 5.84[b]



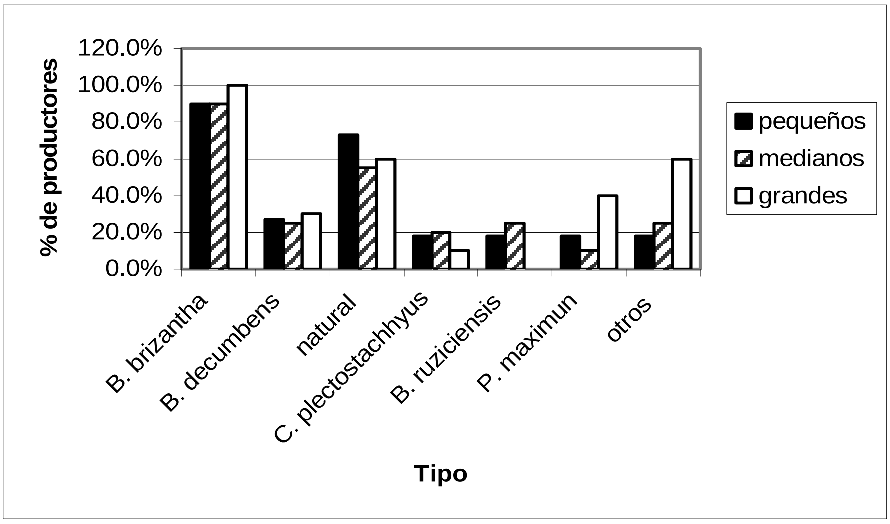
Dendrogram showing a classification of the farmers in the study. Source: Colon 2005.

Pasture types in the area

The composition of the pastures is important in this context because management practices, and in particular burning, is in some cases associated to the pasture dominant species. A se-

[1] Different letters indicate statical differences

ries of introduced grass species have been sown in the area. The first sown varieties arrived to the area in the 1990's: *Brachiaria brizantha*, var Toledo (*B.brizantha*), *B.humidicola* (*B. humidicola*), Guinea grass, *Panicum maximun* var. Mombasa, and *Panicum maximun* var. Tanzania (Ricardo Carrión personal communication 2005). At the beginning African grasses were used primarily by large farmers. The replacement of the natural grasses by introduced varieties has gained interest among famers, being a trend to substitute the grasslands dominated by natural and naturalised grass species with introduced varieties. At present the dominant types are *B. brizantha*, *B. decumbens*, *B. ruzisiensis*, and *P. maximum* var Mombasa. Other introduced grasses with less cover are *Andropogon gayanus* (gamba or ICTA Real), *B. dyctioneura*, *B. mutica*, *Dichantium aristatum* (angleton), *Hyparrhenia rufa* (jaragua), and *B. humidicola*. These are all exotic species to the region, native to Africa. Approximately 90% of the medium and small size farmers and 100% of the large farmers have introduced *B. brizantha* in their farms.



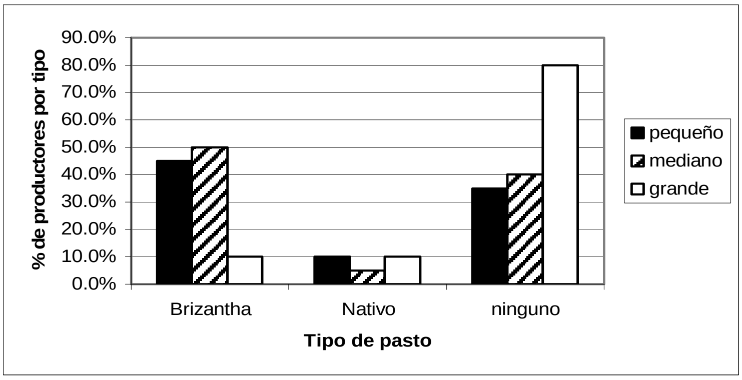
Kinds of grasses and pastures in the farms participating in the interview study. Source: Colón 2005

Pastures and burning practice
The practice of burning is closely associated to the dominant species in the pastures. For example, farmers expressed that species like *Hyparrhenia rufa* (jaragua) and other introduced species such as *B. brizantha* var Mombasa, with seasonal rapid growth (in the rainy season), can lose quality rapidly and become lignified when grazing pressure cannot be maintained to keep a low sward of good quality. The farmers considered that burning was a useful practice to remove plant material of poor quality in these cases.

According to the farmers some grass species need to be burned more frequently than others, but it appears that the frequency of fires has decreased due to a decline in the amount of residual grass. Common species that were burnt in earlier times were *H. rufa (j*aragua*), Cynodon plectostachyus (*estrella*)* and *C. nlemfluensis* (alicia).

The practice of burning in the area
Based on the answers provided by the farmers in the interviews, 5 groups of reasons for practising burning were identified.
1. Burns as a tool to reduce costs in the preparation of the land for agro-pastoral activities: When the first immigrants in El Petén arrived in the area, most of the land cover was forest, except in the area of savannah. One of the requisites to keep the land was to leave a portion of 20% of forest cover and to cultivate the rest. The "Slash and Burn" practice was generally used to clear the land for agriculture or the establishment of pastures. This kind of practice is com-

mon throughout the study area. The small farmers in the area (45 %) use this practice to establish pastures in a rotation system with crops. Medium size farmers (35%) allow cultivation and the use of the practice to other (land-less) farmers. Most of the large farms are in the savannah area where there is no agriculture.



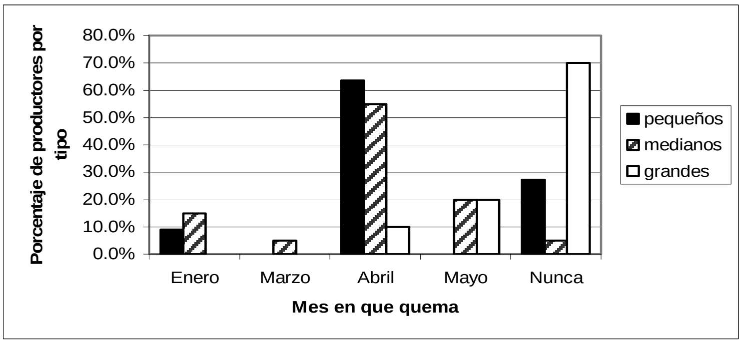
Grasses that are burnt in the study area according to the farmers. Size of the farm: Pequeño (small), mediano (medium) and grande (large). Brizantha (*Brachiaria brizantha*), native (native grassland) and ninguno (no burning).

2. Burns to improve the pasture: This type of use is traditional in El Petén, particularly in the savannah area where extensive cattle raising on natural rangeland is the main land use. The practice is used on natural grasslands to remove old material and also with introduced species of rapid growth, e.g. *H. rufa* and *B. brizantha*. Only 20 % of the large farmers use burning as a practice to improve the quality of the grassland forage. They could be maintained by adequate grazing management and/or by mowing.
3. Burns to control plagues: Farmers reported that earlier burning used to be practiced on large areas in the savannahs to control cattle insect parasites. Today it is used to control insect attacks to introduced pastures and of snakes which hide in the tall grass. Fifteen per cent of the small farmers and 5% of the medium size farmers reported the use of burning to avoid risks of being bitten by the ‘barba amarilla’ (*Bothrops asier*) a common snake species in the area.
4. Burns to control weeds: This practice is used for the preparation of land for cropping.
5. Burns for wildfire control: The practice is used primarily in the areas of savannah where the large areas of grasslands can carry fires in an uncontrolled manner.

Ninety three per cent of the interviewed farmers used burning as a practice in their farm; 49% to improve the pasture quality, 41% to prepare the land for agriculture and 29% to prepare the land for sowing pastures. Forty one per cent of the farmers had only one of the five reasons as a motivation for burning, and only one farmer had the 5 reasons listed above for burning. Most farmers expressed having been affected by fires originated by others.

The farmers expressed that in earlier times burning was associated to hunting activities, for example, to attract wildlife to patches with more nutritious vegetation. Burning was also associated to other extractive activities in the forest, as for example the gathering of honey.

Season of burning
The timing for burning depends on the objective of the farmer. If the purpose of the burning is clearing of the land for cropping, burning will take place at the onset of the rainy season, whereas if the purpose is plague control, burning occurs at the end of the rainy season. Fifty five per cent of the farmers indicated the months of March and April, before the first rains, as the best period for burning.



Percentage of farmers burning at the different months: Enero: January, Marzo: March, Abril; April, Mayo: May and Nunca: Never. Size of the farm: Pequeño (small), mediano (medium) and grande (large).

Disadvantages of burning

Generally the farmers in the area consider that burning is a useful practice and indicate few negative effects. However, farmers showed some concerns. The main negative effects identified were related to the soil. Sixty per cent of the farms indicated that burning led to soil deterioration, loss of fertility and impoverishment. Thirty per cent of the farmers expressed concerns about burning of forests and woodlands, which reduced the provision of material (poles) and fire wood. Also the loss of grass material was a concern. Forty per cent of the farmers expressed that it was convenient to burn but when there were few animals. There seems to be a close relationship between maintaining large number of livestock and burning. When the size of the herds was large, most farmers were concerned about the reduction in the amount of forage. Also, if the number of cattle is high, there is a less need of burning.

Disadvantages of burning expressed by the interviewed farmers in Petén, Guatemala

Farmer type	**Disadvantages of burning**					
	Loss of soil fertility	Death of trees	Loss of grass	Wildfires	Animals suffer	No disadvantages
Small	27%	27%	0%	18%	9%	27%
Medium	25%	15%	40%	15%	25%	10%
Large	60%	10%	40%	30%	10%	15%

Alternative management practices to burning

During the workshop, the farmers were asked to propose alternatives to the use of fire. The options of mechanisation for weed control and clearing are not feasible because of the costs. The farmers agreed that the best practice would be to get organised for a better control of the burning and to avoid wildfires. Some argued that they did not plant trees because of the risk of fires. Chemical control of weeds was used in one case, and it appears to be a relatively low cost alternative. However, other farmers argued that the damage of the soil is worse with the use of chemical than with fire.

When fire was used to control the pasture quality, the farmers proposed a better management of the herds and grazing rotation, for example by reducing the size of the paddocks. They indicated that if the grass was kept short, there would not be a need for burning.

Farmers were sceptical to alternative practices to burning, particularly if they were promoted by agro-enterprises, which tend to focus on profit rather than on good practices for the farmer.

Farmer's knowledge about the effects of burning
It appears that small-size farmers are aware of the problems of rapid loss of fertility after a period of cultivation and also about alternative practices to burning. The main disadvantage of burning is the lack of control of wildfires that is a hinder to investments on the land.

For the medium size farmers, who are organised, the main problem associated with burning is the lack of knowledge about how to improve the management of the pastures. This group of farmers are aware about kinds of pastures and grasses, timing of the burning and the effects on the soil. Several emphasize that an improved management of the grazing rotation and of the herds would reduce the need of burning.

The large size farmers have good knowledge of the grasses (animal preferences, tolerance to plagues and adaptation to different environmental conditions), but they have limited knowledge about which species recover after the fire, probably because they spend little time on the farm. They believe that the re-sprout is too nutritious and not favourable for the rumen flora.

Farmer's knowledge about species resistant to fire
Farmers had different perceptions about the meaning of the word 'resistant' to fire. Some farmers interpreted resistance as the capacity to survive after the fire, others considered that 'resistant' plants were those that could rapidly re-sprout after the fire.

The perception about species resistance to fire also depended on the area where the farm was located. In the savannah, tree species such as *Tapirira macrophylla*, *Byrsoninma bucidaefolia, Metopium brownie and Allophyllus campstostachys* were known to burn, but to survive fires. In the alluvial area, species considered to be resistant were for example: *Calyptrogyne dulces, Spondias purpurea, Dialium guianense, Cordia alliodora, Ficus* spp*., Andira* spp*., Gliricidia guatemalensis* and *Guazuma ulmifolia.* Farmers living in the uplands considered that in the area there were few or no species that were resistant to fire.

Regarding the grasses, some farmers in the alluvial areas considered that the grasslands there do not burn well and in the savannah, farmers considered that the native grasses were resistant to fire and that they re-sprout easily after burning.

Conclusions and recommendations
Livelihood patterns, values, needs and objectives of each farmer group determine their knowledge and the actions they take in their farms. It is important to consider these patterns when designing strategies for the development of the area.

Basically the farmers use burning to lower costs when preparing the land for cropping or sowing pastures. The main problem is the lack of control of wildfires which increases with low levels of education and organisation.

Medium size farmers used burning to improve the quality of the pastures, but a better management of the herds would lead to a reduction in the need of burning. The lack of knowledge in rangeland management was identified as an important limitation for better practices. Capacity building in range management could be a good strategy to reduce the impact of fire in the area.

5 Farmers, trees and complexities – A study of cattle farmers' decision-making process regarding the implementation of silvopastoral systems in El Petén, Guatemala

This chapter is an extract from the thesis by Bente Anfinnsen.

In Central America, more than nine million hectares, 72 percent of all the agricultural land area in the region, is used for livestock production. The area of pastureland is expanding at a rate of four to nine percent annually and half of the present area is considered degraded.

Degradation of pastureland is affecting the livelihood of more than three million people in the region and is contributing to the rapid expansion of this land-use type, mostly at the expense of tropical forest in one of the world's most important hot spots for biodiversity. Despite all this, initiatives for promoting more sustainable production systems among cattle farmers have been limited.

This thesis was based on a four months fieldwork in a research site near El Chal in Petén, Guatemala. From 1960 to the year 2000, the population of El Petén grew from around 25 000 to around 550 000 inhabitants. During the last 40 years, 42% of the forest of El Petén has been converted to agricultural land and pasture.

Silvopastoral systems are land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc) are deliberately used on the same land-management units as animals and pasture with the aim to diversify the production for increased social, economic, and environmental benefits. Research seems to promise that this family of production systems has the potential for being both more ecologically sustainable and economically profitable in addition to diversifying risk. Despite this, implementation of silvopastoral systems has been slow among cattle-farmers in the region and it is natural to wonder why this is so: How are the farmers in the region arriving at their decisions and what factors are influencing their decision-making process?

The research questions of this thesis were:

* To what extent are farmers in Petén implementing silvopastoral systems in their production systems today?
* Which attitudes do farmers in Petén have concerning the use of silvopastoral systems?
* Which factors are influencing the attitudes of the farmers concerning the use of silvopastoral systems?
* Which factors are of importance for converting farmers' attitudes into behaviour concerning implementation of silvopastoral systems in the specific context of the farmer?

Using abduction as the main research strategy and complex theory thinking and classical institutional economics as the main theoretical guidelines, a framework for analyzing decision-making within the field of management of natural resources was designed. Such analytical framework outlines what relations could be expected to exist between the factor groups Attributes of the resource and technology (A), Characteristics of the actor (B), Social institutions (C), Local knowledge, information and training (D), Perceived behaviour control (E) and Requisite opportunities and resources (F), and the different stages of the decision-making process: attitudes towards the behaviour, intentions and behaviour.

The main hypothesis in this thesis was that variables representing all these factor groups are influencing the decision-making process of the farmers regarding the implementation of silvopastoral systems.

Data was collected by using existing data (from a social-economic survey, satellite images and a field mapping) and conducting specific structured interviews (31), transect walks with semi-structured interviews (6), one focus group discussion, unstructured in-depth interviews and participatory observation with cattle farmers in the area and semi-structured interviews with five organisations working in the region.

For achieving triangulation, facilitation and complementation in this research it was chose to use multiple methods also for data analysis combining qualitative analysis (grounded theory, coding and narrative analysis) and quantitative analysis (descriptive statistics, correlation analysis, stepwise regression and factor analysis). For being able to employ quantitative analysis in identifying what factors that are influencing the decision-making process of the farmers, indices measuring the farmers' attitudes and behaviour were constructed. All through the data collection process and analysis it was kept in mind the adductive ideal of that a research process should be dynamic and iterative.

Concerning the first research question; To what extent are farmers in Petén, Guatemala implementing silvopastoral systems in their production systems today? both qualitative and quantitative analysis confirm that all farmers have some silvopastoral elements in their farm and do enjoy a certain level of social, economic and/or environmental benefits from this. The levels of implementation of silvopastoral systems and the benefits harvested are however very variable. The potential for further implementation is great for all the farmers. Compared to the potential of intensification and diversification that silvopastoral systems may have, there should still be a great unfulfilled potential of optimising the economic, social and environmental benefits attained in the region. One clear trend in the present situation of implementation is that few of the farmers commercialize products from the woody perennials on their farmland. The production of tree-products is almost exclusively aimed at own consumption or for being self supplied with production inputs to the cattle production.

Related to the next question; which attitudes do farmers in Petén, Guatemala have concerning the use of silvopastoral systems? The conclusion is that all farmers are positive towards at least a certain level of implementation, but that the variation between farmers is also great. Asking farmers to prioritise satellite images of paddocks with different levels of implementation got an indication of that their attitudes towards silvopastoral systems should correspond to a higher level of implementation of silvopastoral systems than the case is presently in their farms. All but three of the farmers were of the opinion that having trees on the pastureland give more benefits than disadvantages. The most frequently mentioned benefits from the trees are shade for the animals, firewood for the use of the household, wood for construction for the use of the household, poles for making dead fences, fruits, seeds and leaves as fodder for the cattle, living fences, and that some shade is good for the pasture. The most frequently mentioned disadvantage of having trees on the pastureland was that too much shade inhibit the growth of the grass, although some farmers specified that it depends on the tree species if the shade is damaging or not. Generally also the attitudes of the farmers are most focused on the usefulness of the trees for consumption and production inputs to the cattle production. However, several farmers mentioned as well the production of environmental services and public goods as benefits given by trees.

The analysis related to the two last research questions; Which factors are influencing the attitudes of the farmers concerning the use of silvopastoral systems? and Which factors are of importance for converting farmers' attitudes into actions concerning implementation of silvopastoral systems in the specific context of the farmer? gave interesting results both related to the choice of methods and theoretical framework and regarding the concrete variables and their influence on the farmers' decision-making.

In the quantitative part of the analysis, a set of four stepwise regression analyses were conducted. Slight modifications of the sample and variations between only backwards elimination and also forward addition produced diverging results. This analysis shows clearly the strength of using a holistic model and exploring a wide range of variables. If only focusing on a narrow model and one method of analysis, it is easy to end up with a correspondingly narrow picture of the world. The sensitivity of the statistical analysis applied also emphasizes the strength of combining quantitative analysis with qualitative data collection and analysis. In a complex world, it is generally beneficial to have more than mathematical patterns as the basis for interpretations.

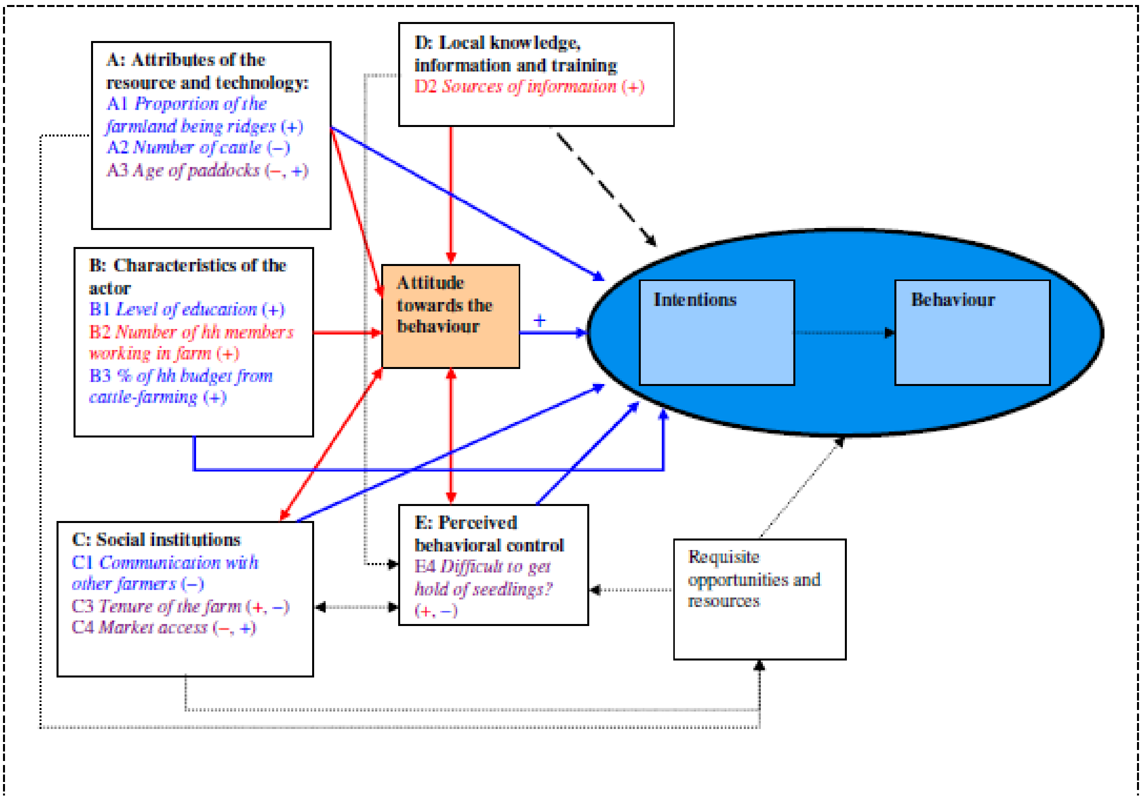


Figure: *Framework for analysis of decision-making* *within the field of management of natural resources employed in this thesis. Variables found significant in the regression analysis to influence attitudes and intentions/behaviour are highlighted in red and blue respectively. Variable with names in purple were found to influence both attitudes and behaviour.*

In the figure above, is illustrated the analytical framework applied and the relationships quantitatively demonstrated by regression analysis are highlighted with red and blue arrows. The dashed line demonstrates the only relation not found statistically significant in the regression using my complete sample (although it was significant in alternative analyses). The dotted lines illustrate relations that are not tested quantitatively, but demonstrated as likely through qualitative analysis. These relations may not be systematic, but examples of such interaction do indeed exist and the possibility of inter-linkages may not be excluded. The main hypothesis was thereby confirmed; variables representing all the factor groups in the framework for analysis are indeed influencing the decision-making of the farmers related to the implementation of silvopastoral systems.

It was also demonstrated through the combination of qualitative and quantitative analysis that all the three stages in a decision-making process in the analytical framework; attitudes, intentions and behaviour seem to have a role to play. There is a clear, positive relation between having positive attitudes towards implementation of silvopastoral systems, developing intentions for implementation and the actual behaviour of implementing these diversified production systems. Regression analyses show however that the same variables in many cases influence the attitudes and the behaviour of the farmers in different directions. This observation is a confirmation of the decision-making of the farmers being a complex process and makes it important to be cautious to distinguish between the effects the variables have on attitudes and their direct and indirect effect on behaviour respectively. The fact that no variables representing biophysical factors or conditions determining opportunities and resources gave a consistent direction of influence on the decision-making process supports that the technology can be adapted to a wide range of natural and social conditions. This is promising for the future fulfilment of some of the potential for optimizing the economic, social and environmental benefits silvopastoral systems may give in a region.

6 Characterization of silvopastoral pastures in Muy Muy, Nicaragua

This chapter is an extract from the MSc theses by Sonia Ospina and Jimena Esquivel.

Pasture composition

The natural vegetation in the region of central Nicaragua corresponds to a transitional tropical sub-humid forest (Holdridge, 2000) with semi-deciduous vegetation, and referred in Bullock *et al.* (1995) as seasonally dry tropical forest. The pastureland vegetation that has been studied is an assemblage of native and naturalized species including grasses, herbs and woody plants. We have used the term semi-natural grasslands to refer to a pastureland area covered by spontaneous vegetation that grows naturally after forest clearing or on fallow land and which is maintained by grazing management (basically fencing and weed control).

At present, the majority of the livestock production in Nicaragua is based on grazing of this spontaneous herbaceous vegetation. In Nicaragua, the semi-natural grasslands occupy more than 90% of the area dedicated to livestock production and therefore represent the basic resource in silvopastoral systems, particularly when the capacity for investments in the form of infrastructure and resource supply (fertilisation and irrigation) is low. They constitute an important resource under marginal land use exploitation (McIvor 1993), and can provide various services including buffering against extreme events such as plague attacks (Holman and Peck 2004) and droughts. Regionally they constitute a reserve of species adapted to the local environment and to grazing (Fisher *et al.* 1992). Despite their importance in sustaining livestock production there is little knowledge about these grasslands in the region, both in terms of their composition and critical functions such as primary productivity and seasonality the production.

In the region, there is a clear contrast between the rainy and dry periods. Rainfall recorded between November/December to April/May is usually less than 10% of the annual mean (1500 mm). Rainfall seasonality is the most conspicuous feature of the climate which shapes the functioning of the productive system. The soils in the area are spatially variable (CATIE-NORUEGA 2009) and this variability is likely to influence the composition and richness of the grasslands. Another factor with important effects on the composition of the vegetation is the grazing regime, i.e. frequency, intensity and degree of selectivity by the cattle (Rusch & Skarpe 2009).

This investigation aimed to: i) describe the herbaceous vegetation in semi-natural grasslands in silvopastoral systems in the Central region in Nicaragua, ii) study how the vegetation varies under two different soil conditions, iii) between rain and dry seasons and iv) under two types o cattle management.

The area of the study

The study was conducted in the area of Muy Muy, Nicaragua, at an altitude between 200 and 400 masl. The climate is seasonal with a wet period between May and October and a dry season between November and April. Mean annual rainfall is 1500 mm.

The vegetation was described in two landscape units, the undulating plains at intermediate altitudes and the floodplain of the Río Grande de Matagalpa river. The intermediate plains soils have high contents of clay and drainage is at times limited. (CATIE-NORUEGA 2009). The soils in the floodplain consist of alluvial deposits which have the highest contents of P and K in the area (CATIE-NORUEGA 2009)

Also two types of management of the herds are common in the region, namely herds are divided into ‘milking cows’ and ‘non-milking cows’[2]. The two herd types graze on different pastures, usually under different grazing pressures and rotation times. The kind of breeds used in the region are generally crossings of European and Asian races, *Bos taurus* x *Bos indicus*

The grasslands were studied in 3 units with different combinations of soil fertility and herd management: 1) units in the intermediate plains used by milking cows (PI – Milk), 2) units in the floodplain used by milking cows (Vega- Milk) and 3) units in the intermediate plains used by ‘other cattle’ (PI – Other). In total 24 paddocks, covering approximately 190 ha.

Floodplain

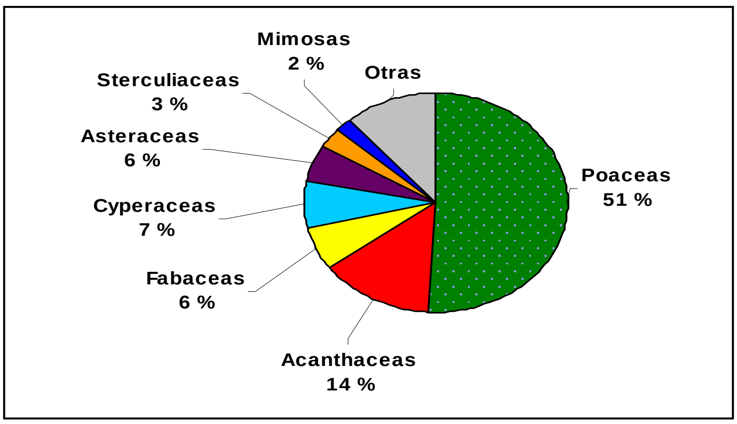
Intermediate plains

Photos: S. Ospina

Results

The grasslands are species rich plant communities and are composed primarily by species native to Central America (ca 75 % of the plant cover). A total of 158 herbaceous species were recorded, 36 species in the grass family (Poaceae) which made up to 51 % of the total number of species. Forty two per cent of the plant cover is concentrated in 4 species of grasses and one forb: *Panicum maximum, Paspalum notatum, P. conjugatum, P. virgatum and Blechum pyramidatus.*

Plant families



Relative contribution of plant families to the composition of semi-natural grasslands in the area of Muy Muy, Central Nicaragua. Source: Ospina *et al.* 2009.

[2] All other cattle in the farm that are not milking (calves and steers) hereon “non-milking cattle” .

Different properties of the environment and management characterised the land units in the study. In the floodplain, paddocks received a larger number of weedings (i. e. mechanical removal of undesired plants) per year, and had higher number of cattle per unit area. They have also smaller areas and have lower tree cover compared to the intermediate plains paddocks used by more extensively by non-milking cows.

Paddock characteristics	P.I. - Other	P. I. - Milk	Floodplain	P
Nr of weeding per year	2.13^{a}	2.45^{a}	3.07^{b}	0.0017
Area flooded in wet season (%)	4.88^{a}	27.00^{b}	2.80^{a}	0.0014
Animals/ha (UAha^{-1})	0.52^{a}	0.70^{a}	1.15^{b}	0.0020
Tree cover (%)	13.23$_{b}$	9.87^{ab}	7.41^{a}	0.0192
Occupancy per year (nr days)	168.45^{a}	116.21^{a}	140.64^{a}	0.0998
Presence of wáter source	3.32 ^{a}	3.37 ^{a}	4.03 ^{a}	0.2773

Different letters indicate statistical differences, $p<0.05$

The position in the landscape, the grazing management of the herds, the season, the number of animals/unit area, the proportion of flooded area in the wet season, the size of the paddocks and the degree of tree cover, were factors that explained differences in grasslands composition.

The floodplain were characterised by grass species with attributes that have a correspondence with what is expected for species growing in soils of high fertility. In the intermediate plains there was predominance of various native grass species of the genus *Paspalum* sp. and one exotic sown pasture grass, *Dicanthium aristatum* (angleton). Annual and short lived species, with attributes that are commonly associated with overgrazing, were more frequent in the paddocks used by 'other cattle' than milking cows. The presence of these species is also indicative of a loss of the grassland quality. The grasslands used by these herds are generally managed more extensively, paddocks are larger, the rotation regime is less regular, and during the dry season are often used without a particular rotational system. These results indicate that poor management of these pastures is likely contributing to the maintenance of grasslands of poor quality, and that the history of use is most likely an important factor determining the composition of the grassland.

The potential of natural regeneration of trees in silvopastoral systems

The long term sustainability of silvopastoral systems require that new individuals of trees are recruited at a pace that compensates mortality and harvest. It has been demonstrated that remnant trees in silvopastoral systems in tropical humid areas can contribute to the recruitment of tree saplings (Guevara *et al.* 2004). The magnitude of the natural regeneration of trees in the seasonally dry systems in Central Nicaragua is unknown. This study aimed to assess the composition and abundance of trees of different development stages (adults, saplings and seedlings) in paddocks under active grazing in Muy Muy, Matagalpa.

Most of the common tree species in the area appear to be able to recruit abundantly despite the grazing pressure in the paddocks. However, different species have different capacities to recruit. Approximately half of the tree and shrub species can regenerate naturally under current grazing management practices. The species that most commonly regenerate are species that colonize in forest openings, i.e. that require or tolerate high levels of light, whose seeds are disperse by wind or cattle. For these species, it is possible to design management plans that take into account the natural recruitment of trees in the paddocks. Some of these species, such as *Cordia alliodora, Tabebuia rosea, Platymiscium parviflorum, Cedrela odorata, Cordia collococca, Tabebuia ochracea, and Pachira quinata* have high timber value. Others, are often used as fodder or planted as live fences: *Enterolobium cyclocarpum, Guazuma ulmifolia, Albizia* *saman, Albizia guachapele, Gliricidia sepium, Pithecellobium dulce*, *Psidium guajava, Acrocomia mexicana, Erythrina berteroana* and *Bursera simarouba*.

The species with little capacity to recruit naturally are typical of closed woodland or forest, and seem to tolerate poorly either the competition of the pasture vegetation, the grazing and trampling pressure, or both. The recruitment of these trees was limited at different stages. In some cases, it appears that the production and dispersal of seeds is the limiting factor, which indicates that the current populations would not be viable in the long run. For other species, the limiting stage appears to be the establishment phase. Despite that the seeds are dispersed into the paddocks there is little germination of seeds and sapling establishment. This limitation could be either due to physical damage of the seedlings by cattle or by a limitation of suitable sites for germination and establishment.

Most common 12 tree and shrub species (dbh > 10 cm) and their habitat affinity (riparian forest (Br), secondary forest (Bs), disturbed areas (Ap) and crops (C)). Seed dispersal vectors (wildlife (As), wind (V) and cattle (G)), Potential uses (forage (Fo), timber (M), firewood (L), shade (S), live fences (Cv) and fruits (Fr)), and 'Importance Index (IVI) in 46 paddocks in Muy Muy, Nicaragua. Source: Esquivel *et al.* 2009.

Species	**Common name**	**Habitat**	**Dispersión**	**Usos**	**IVI adults**	**saplings**	**seedlings**
Guazuma ulmifolia	guácimo	Br, Ap	As,G	Fo, M,	82*	109*	99*
Cassia grandis	carao	Ap	G	S	80*	83*	46*
Tabebuia rosea	roble	Br, Bs,	V	M	80*	78*	99*
Albizia saman	jenízaro,	Bs, Ap	G	M,Fo,S	74*	58*	33*
Bursera simaruba	jiñocuabo	Br, Bs,	As	L,Fo,	63*	18*	41*
Enterolobium cyclocarpum	guanacaste	Bs, Ap	G	Fo,S	52*	108*	91*
Cordia alliodora	laurel hor-	Bs, Ap	V	M	47*	48*	84*
Leucaena shannoni	frijolillo	Ap	G	Fo	45*	57*	48*
Gliricidia sepium	madero	Bs, Ap,	G	Fo, Cv	40*	31*	28*
Spondias mombin	jobo	Ap, C	As	Fr,Cv	37*	24*	31*
Cedrela odorata	cedro	Bs, Ap	V	M	34*	9	48*
Cordia collococca	muñeco	Bs, Ap	As	M,Fo-	25*	41*	26*
Platymiscium parviflorum	P. parviflo-	Bs	V	M	24*	34*	37*
Psidium guajava	guayaba	Ap, C	As, G	Fr,Fo	22*	55*	18*
Genipa americana	jagua	Bs, Ap,	As	Fr	14*	31*	53*
Pithecellobium dulce	espino de	Br, Ap	As, G	Fo,L	7	43*	7

IVI adults = relative abundance + relative frequency + relative dominance

IVIs juveniles y plántulas = relative abundance + relative frequency.

*The 10 largest IVI o IVIs per category

7 Responses of natural and exotic pasture productivity to rainfall

This chapter is an extract from the PhD dissertation by Sonia Ospina

Conversion of natural ecosystems for agro-pastoral use is one of the major causes of change in the biotic composition of ecosystems globally (Rockström *et al.,* 2009). These shifts can result in significant changes in bio-geochemical cycles (Garnier *et al*., 2007; Hooper *et al*., 2005). In the humid and sub-humid Neotropics, forests modified to produce grasslands to support livestock farming are some of the most widespread pastureland types (Sarmiento, 1984; Fisher *et al*., 1994; Maass, 1995). These formations characterize a silvopastoral landscape consisting of a matrix of grasslands with some tree cover (Harvey and Haber, 1999). The grasslands are mainly unsown wild herbaceous communities, 'semi-natural grasslands', i.e. their plant communities are natural, with a predominance of various prostrate grasses of the genus *Paspalum* spp. (Ospina *et al.,* 2009) and are maintained by grazing and clearing of the woody vegetation. Their large extent implies that they have a significant role in the global carbon cycle but their contribution is not well understood because of the paucity of high quality data on primary productivity and limited information about their ecological characteristics (Scurlock *et al.,* 2002; Baruch, 2005). In much of tropical America, these pastureland types occur in areas where the natural vegetation has been classified as seasonally dry forest, characterized by a strong seasonal growth pattern determined by the distribution of rainfall (Sarmiento and Pinillos, 1999).

Primary productivity and total rainfall correspond closely in sub-humid and arid regions (Knapp *et al.,* 2006; Baeza *et al.*, 2010). An understanding of the response of ANPP to rainfall becomes especially important in view of the predicted changes due to global warming. For Central America, scenarios for the dry and wet seasons predict a relative decrease in rainfall of 10 and 20%, respectively for the period 2090-2099, relative to 1980-1999 (IPCC 2007).

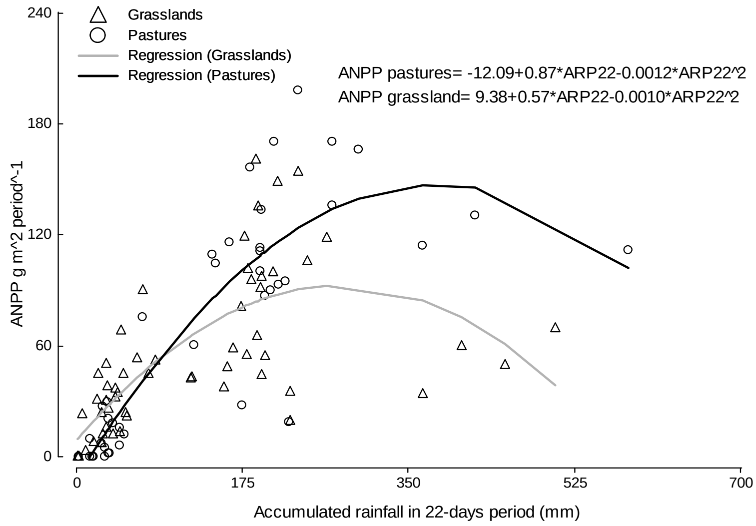
In seasonal climates, primary productivity is affected not only by the total annual or seasonal rainfall, but by rainfall distribution as well (Camberlin *et al.*, 2009; Snyman, 2009; Swemmer *et al.,* 2007). The research question was then whether these patterns affected the primary productivity of the grasslands in the silvopastoral systems in central Nicaragua.

At local levels, the composition of the vegetation can be an important determinant of productivity (Hector *et al.*, 1999). This knowledge is important, particularly because human interventions often consist in the replacement of the vegetation cover. In Central America, as in other areas with sub-humid and seasonal climates (Dias-Filho, 2007) savannas and grasslands are often replaced by sown pastures with the aim to improve the amount and quality of the feed offered to cattle. In the area of Muy Muy, these shifts consist essentially on a replacement of the vegetation cover without changes in resource supply (water and nutrients). The change in the composition of the pasture may have significant impacts on ecosystem function depending on the particular attributes of the dominant species.

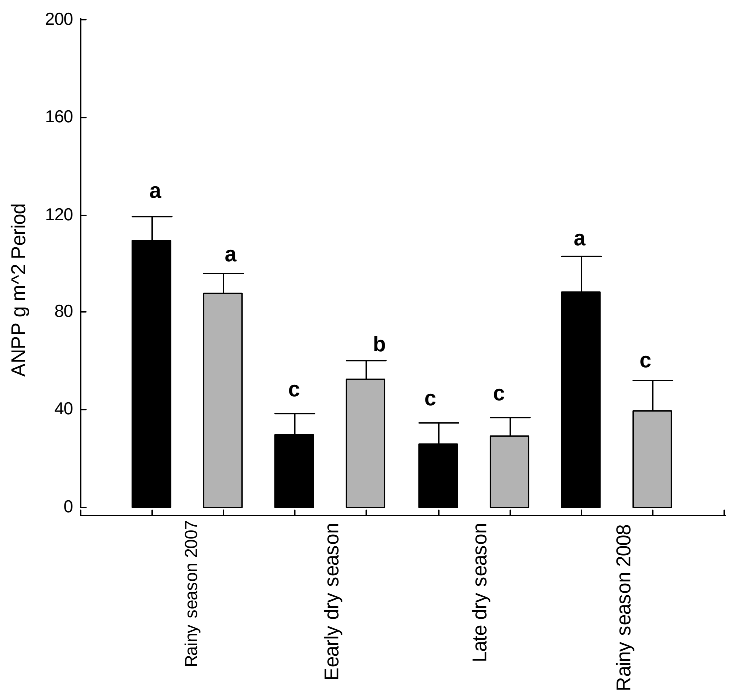
The seasonal and annual productivity and the stability in production of multi-species grasslands with sown pastures of the exotic species *Brachiaria brizantha* were compared. The specific questions were: (i) whether ANPP in pasturelands in Central Nicaragua were related to rainfall and its distribution over short time periods; (ii) which rainfall parameters best explained the variation in ANPP; (iii) whether the ANPP of sown pastures was higher than for semi-natural grasslands, when rainfall parameters in the dry and the rainy seasons were controlled for; (iv) whether grasslands show a more stable ANPP along the season than sown pastures; and (v) what was the annual ANPP for grasslands and sown pastures. The sites of the study correspond to the descriptions of the Muy Muy area in the previous sections.

Results

Grassland productivity was positively associated to cumulative rainfall. This finding is consistent with empirical evidence from most grasslands and savannas of the world showing a correspondence of productivity with between and within year variability in the amount of rainfall. However, productivity was low when rainfall was higher than ca. 300 mm in a period of 22 days. Apparently, the timing and intensity of the rainfall events were important in determining when productivity decreased with rainfall. This decline seems to have occurred when large volumes of water fell within a month, which in the case of this study, coincide when soils are dry and when high surface run-off is expected, so rainfall do not infiltrate.



Relationships between above-ground net primary productivity (ANPP) and cumulative rainfall in a period of 22 days (ARP22) for sown pastures and grasslands. Sown pastures: n= 44, adjusted r^2= 0.74; grasslands: n= 60, adjusted r^2= 0.47



Mean values and standard error of above-ground net primary productivity (ANPP) for the different types of pastureland in different seasons ± 1 SE, based on LSD test. Significant differences ($p<0.05$) between treatments are indicated by different letters. *Brachiaria* spp.pasture, grey bars and semi-natural grassland, black bars. Source: Ospina *et al.* (manuscript in preparation

The combination of large rainfall events and low soils permeability were probably the reasons for low infiltration of rainfall in the soil, and low water supply for the vegetation. in addition to the amount of rainfall, productivity responded to how rainfall was distributed. Productivity was positively related to more frequent and more evenly distributed rainfall events in both grasslands and sown pastures.

Despite more rapid growth in the rainy season, sown pastures appear to have stopped growth more abruptly at the end of the rainy season and, during the dry season, low rainfall translated into significantly lower levels of productivity than in grasslands. This pattern could be attributed to the occurrence of species in the grassland assemblage with attributes that enable them to maintain growth when water supply becomes limiting.

The result of a more defined peak of production of the *Brachiaria* pastures in the rainy season compared to the grasslands is also reflected in higher values of temporal stability. These results coincide with those reported in other studies about higher temporal stability of aboveground biomass in grasslands than in sown pastures, and further demonstrate that grasslands stabilize function in time more than sown pastures. As shown in earlier studies, the higher stability in grasslands could be explained by the presence of a higher number of species and possibly of higher functional diversity.

Conclusions

To our knowledge, this is the first study that has quantitatively assessed annual and temporal fluctuations in ANPP in these grasslands and pastures, where the access of grazing animals has been controlled. Data from earlier studies have focused on sown pastures only and used standing biomass as a surrogate for productivity. The methodology has enabled a more accurate assessment of ANPP and the of factors underlying ANPP change. Understanding the outcome of predicted rainfall distribution in climate change scenarios remains a significant challenge for predicting the amount and the seasonal variability of ANPP for grassland but more so for sown pastures because to their sensitivity to rainfall amount and its distribution. Following the findings of this study, the introduction of sown pastures in the area of the study appears to be unjustified, when seeking to increase ANPP, since there appears to be no significant gains on an annual basis. Sown pastures show more variability within seasons, and there is an indication that they may be more sensitive to variation in the distribution of rainfall. Sown pastures were slightly more productive in the rainy season, and the surplus produced in this period could be used in the dry season through harvest and storage. If this practice is not implemented, more uneven seasonal production is likely to impose extra challenges to the grazing management by livestock. The gains of replacing grasslands with sown pastures appear to be marginal and should be weighed against increased costs and the ecological and environmental risk of land cover transformations with monocultures. However, aspects about quality and nutritional value of the different types of pastureland need to be considered as well.

8 Responses of native and introduced pasture plants to drought and defoliation

This chapter is an extract from the PhD dissertation by Lester Rocha

How grassland species respond to grazing and drought are key determinants of the persistence of species in silvopastoral systems in seasonally dry climates. How two common species in the grasslands of silvopastoral systems in central Nicaragua, one native of Central and South America and the other, an exotic naturalized species were examined.

Panicum maximum and *Paspalum notatum* are widely distributed and abundant in tropical and subtropical grasslands and are known to be important fodder grasses for cattle. *Panicum maximum* Jacq. is native of Sub-Saharan Africa, but widely naturalised in the neo-tropics. It has an erect growth form, loosely to densely tufted, with short rhizomes, and rooting at the lower nodes. *P. maximum* grows in well-drained, moist and fertile soils, although some varieties are tolerant to lower fertility and poorer drainage (Cook *et al.* 2005). On the other hand, *Paspalum notatum* Flüggé is native to the Neotropics, widely distributed from North to South America. It is sward-forming, with fibrous rhizomes, short internodes, and bearing shoots and deep fibrous roots at the nodes. *P. notatum* grows in a wide range of soils from light- to heavy-textured. Although it prefers fertile soils, it can maintain dense stands on infertile soils, probably due to nitrogen fixation in the rhizosphere (Cook *et al.* 2005).

Paspalum notatum growing in paddocks from the intermediate highlands (nutrient-poor site) in Muy Muy, Nicaragua. Source: Rocha, L. 2009.

Panicum maximum growing in paddocks from the floodplain of the river Río Grande de Matagalpa (nutrient-rich site) in Muy Muy, Nicaragua. Photo: Sonia Ospina.

The aim of the study was to evaluate the functional responses on populations from different provenances of two perennial grasses to simulated grazing and resource supply.

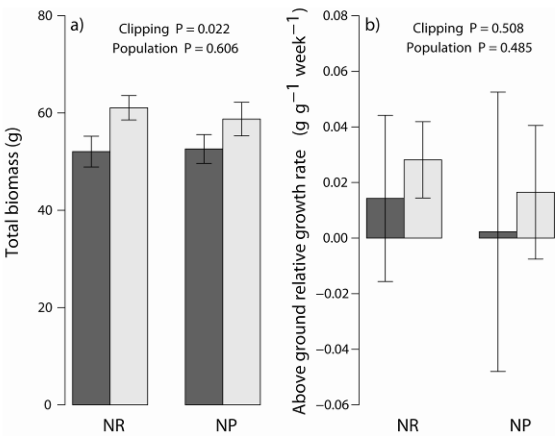
The specific objectives of these studies were:

- To assess the levels of tolerance in the two species and their populations to two levels of clipping and the correspondence of such responses with functional attributes that are related to plant growth and resource acquisition as well as to within-plant resource allocation. We also explored the relative importance of a group of plant traits in determining tolerance and the strategies expressed by each species to cope with clipping.
- To test experimentally the predictions of the current models that simulate responses of plants to loss of green tissue for two focal resources, nutrient and water availability, on plant tolerance to high (every 3 weeks) and low (every 6 weeks) clipping frequencies on populations of the two grass species

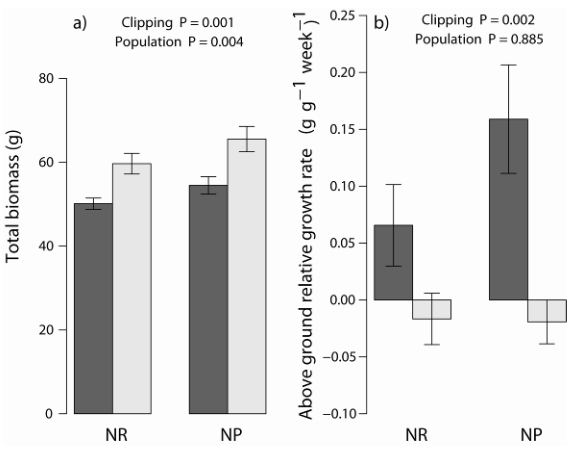
Results

Inter- and intraspecific variability in tolerance

Both species, *Panicum maximum* and *Paspalum notatum* showed similar changes in total biomass (above- and below-ground) in response to clipping. Also the response of populations originating from nutrient rich (NR) and nutrient poor (NP) habitats was similar in both species. However, there were differences in growth rates between the species. *P. maximum* had comparatively higher relative growth rates at high clipping intensity, but in the case of *P. notatum*, there as a significant decrease in growth at high clipping intensity.



Mean (± 1 SE) and P-values of: **a)** total biomass and **b)** above ground relative growth rate of nutrient-rich (NR) and nutrient-poor site (NP) populations of *P. maximum* growing at high (black bar) and low (gray bar) clipping frequencies. Source: Rocha 2009



Mean (± 1 SE) and P-values of: **a)** total biomass and **b)** above ground relative growth rate of nutrient-rich (NR) and nutrient-poor site (NP) populations of *P. notatum* growing at high (black bar) and low (gray bar) clipping frequencies. Source: Rocha 2009

These results support the hypotheses that plants in resource-rich environments and with grazing tolerance traits are likely to have greater flexibility in growth and nutrient uptake than plants in resource-poor environments, they can therefore re-sprout faster after herbivore damage. At the population level (within species), tolerance was determined by the time available for recovery after clipping.

Clipping frequency altered several plant traits in both species and populations, suggesting that defoliation rate and genetic differentiation between populations have to be taken into account when trying to predict plant responses to grazing. To better understand the most essential processes that determine tolerance to grazing and the variation on plant strategies, a concerted amount of functional traits including belowground organs such as rhizomes should be considered.

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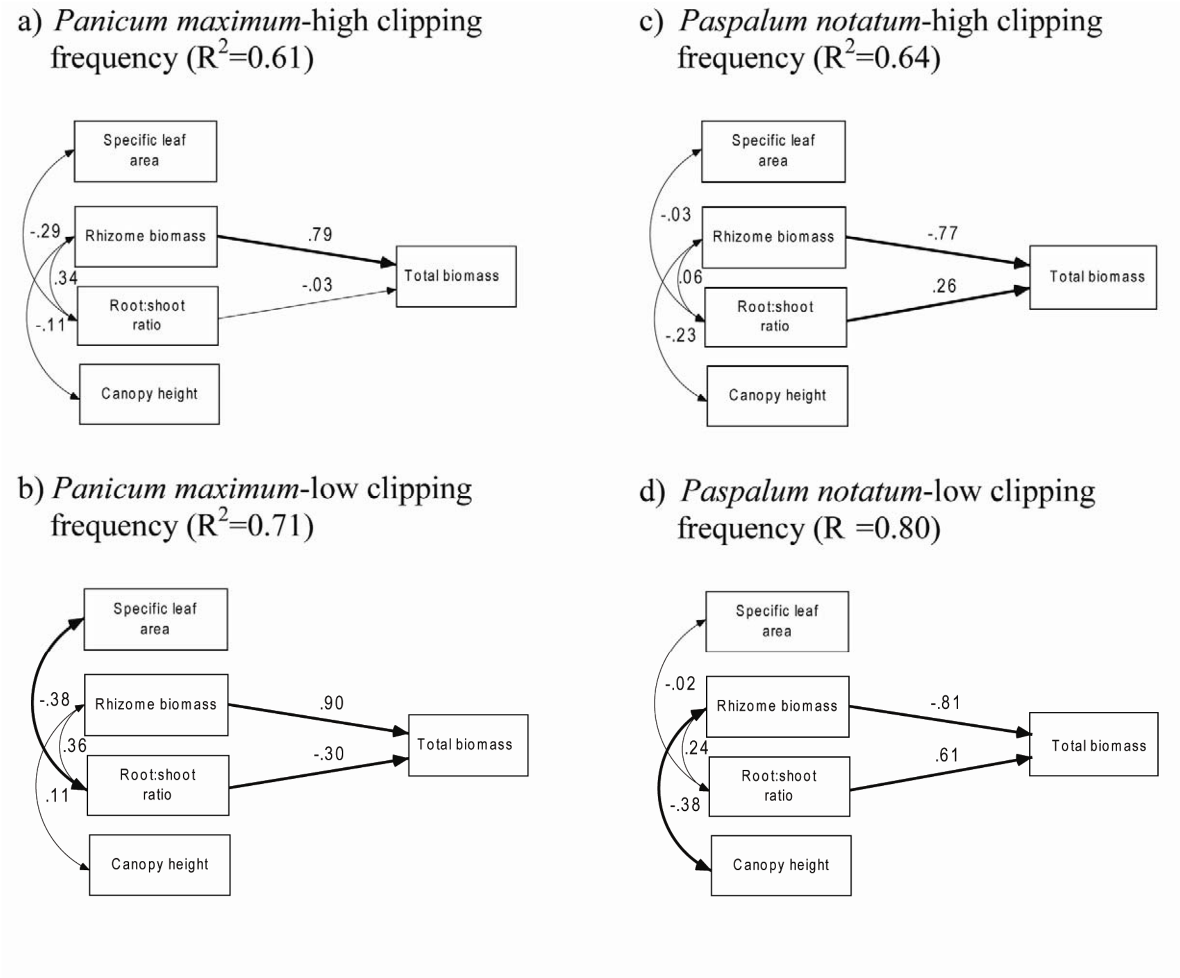


Plant attributes associated with the response to two frequencies of clipping, measured as total plant biomass at the end of the experiment. Path diagrams for the effect of clipping frequency on functional traits and total biomass (tolerance) in *P. maximum* (**a**,**b**) and *P. notatum* (**c**,**d**). Thick arrows indicate statistically significant differences ($P < 0.05$). Double arrows indicate linear correlations. Source: Rocha 2009.

Conclusions

The interacting effect of clipping frequency and resource availability regulated plant performance of *P. maximum* and *P. conjugatum,* and their ability to recover tissue loss. This study showed that plants responded differently to nutrient and water availability and that the clipping frequency alleviated or aggravated the resource limitation on the plants. Therefore, it is difficult to predict with a high degree of certainty the tolerance level among species by using generic models. Functional traits varied between clipping frequencies and resource availability, so complex patterns emerged. However, the two species showed correspondence between the functional attributes and their responses. It also showed that leaf traits with a strong correspondence with the plant's resource economy were modified by clipping frequency at varying resource availability. Moreover, evidence of genetic differentiation between populations that could influence plant tolerance was presented, and hence, the different plant functional traits assessed. However, genetic differentiation among populations was not constant and neither clipping frequency nor resource availability was acting similarly in both species. This supports the idea of the existence of a multiple-trait trade-off varying along a continuum of plant functional traits and a continuum of plant responses to defoliation.

Plant responses to herbivory are complex and further work is needed to advance our fundamental understanding of the processes influencing plant tolerance at varying resource availability Thus, it is imperative to design experiments comparing the responses to defoliation of other native and naturalized species under natural conditions. Moreover, knowledge of the variability of functional attributes of native and naturalized grasses is still needed for better select plant traits related to grazing. Additionally, within-species variability can ensure a species to occur at a wide range of situations along the resource availability – defoliation gradients. This is probably the strategy of widely distributed species. Therefore, studies to examine intraspecific variability of widely distributed native and naturalized species are essential.

9 Interactions between trees and grassland

This chapter is an extract from the thesis by Harold Gamboa

Trees and pastures interact in various forms, through competition and facilitation mechanisms, being the net balance of the interactions a result of the environment and the properties of the species of trees and herbs involved. A net facilitation effect of trees on the understory vegetation has been observed particularly under conditions of environmental stress, for example in arid areas or in unusually dry years. Under these conditions, trees can reduce evapotranspiration in shaded plants and reduce stress by water limitation. On the other hand, trees can affect negatively the productivity of the pasture, mainly through the competition for light when understory plants have high demand of light, and or by a reduction of water availability in the soil through rainfall interception and root competition. These interactions are not well known in the silvopastoral systems in Central America, although dispersed trees in paddocks for grazing is a common feature in these landscapes.

This study examined the effect of the shade provided by two species commonly found in silvopastoral systems in Nicaragua, *Albizia saman* Jacq. (A. saman) and *Platymiscium parviflorum* Benth. (P. parviflorum) on the aerial net primary productivity, plant community composition and the nutritive value of 14 grassland plant species.

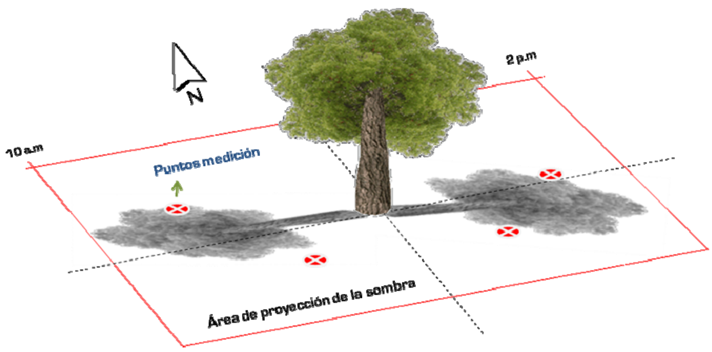
Productivity was studied in semi-natural grasslands of Muy Muy, Matagalpa, Nicaragua, an area with strong climatic seasonality, as described in chapters 5 and 6. Biomass samples were collected during a period stretching from the dry season to the onset of the rain season.

Trees can affect understory plants depending of their attributes, for example, tree architecture such as shape, height, crown type (depth, density and width), lowest branching height and leaf phenology (whether the foliage is evergreen or deciduous). These properties affect the amount of radiation that reaches the ground. Most of the tropical pasture species require high radiation for optimal photosynthesis (associated to the C4 photosynthetic pathway), at the same time that they are tolerant to high temperatures and water deficits. It is therefore likely that growth will be limited by the shading of trees, although some species are known to adapt to low radiation (such as the grass *Panicum maximum* and legume species).

Primary productivity is a fundamental process in ecosystems since it is the rate by which the energy of radiation is captured by plants, transformed and made available to other trophic levels in the ecosystem. It is a primary function of the vegetation; it acts as an integrative attribute of various aspects of the functioning of ecosystem and determines the carrying capacity of ecosystems.

Methods

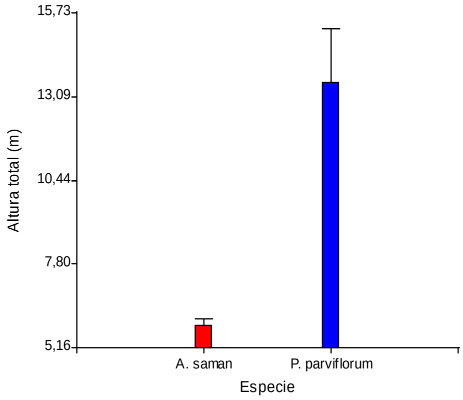
Biomass samples were collected under the tree canopies and in the open grassland at 21 days intervals, using cages to exclude grazing. The composition of the grassland was also observed at each sampling time. The percentage of crown cover was estimated at each sampling period using a densitometer.

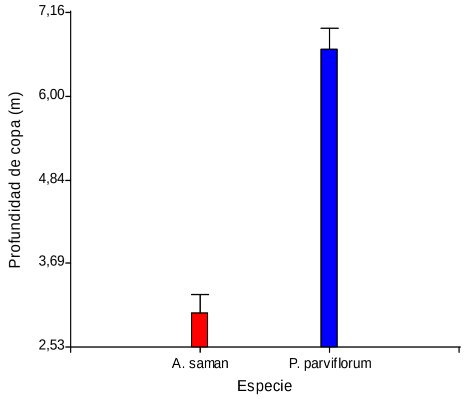


Distribution of biomass sampling and vegetation analyses points under the tree canopy, after modeling the area of shading using the ShadeMotion software. Source: Gamboa 2009

Results

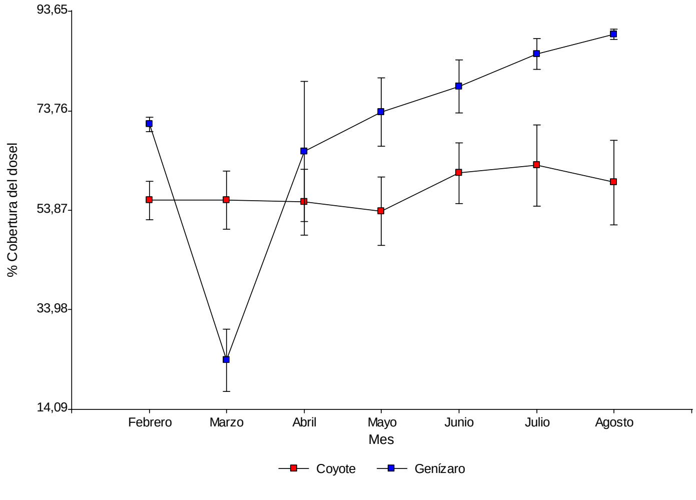
The two tree species differ in morphology, they differed in height and in crown depth. *P. parviflorum* trees were taller and had deeper crowns but there were no differences between species in crown diameter.





Tree height (left) and crown depth (right) of A. saman and P. parviflorum. Bars indicate mean values ±SE. Source: Gamboa 2009.

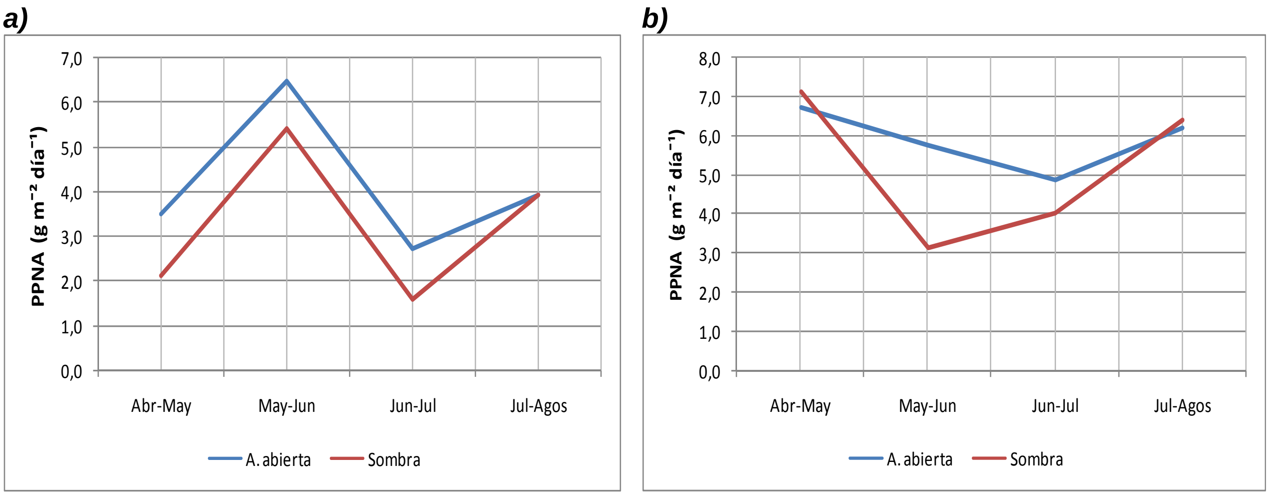
Foliage retention in *P. parviflorum* was more stable during the dry and rainy seasons (57,8% shading, in average); whereas, despite maintaining a higher percentage of shade in average for the two seasons (69,6%). *A. saman* showed a strong felling of leaves during the dry season –specially in March-, resulting in important variations in shading along the year.



Seasonal variation in crown cover (in percentage) in A. saman (blue symbols) and P. parviflorum (red symbols).Mean values ± SE. Period from February to August. Source: Gamboa 2009.

Regardless of tree species, productivity of the grassland was lower under the trees. The total productivity under the shade of *A. saman* was in average 5,18 g m^{-2} day^{-1}, whilst under *P. parviflorum* the average was 3,3 g m^{-2} day^{-1}. During the dry season, there were no differences between the productivity under the tree and in the open grassland.

Pasture ANPP under *P. parviflorum* was at all times lower than in the open. In contrast, pasture unders under *A. saman*, was lower a the onset of the rainy season, but increased considerably and reached similar ANPP values than in the open in two periods in the rainy season (June-July and July-August).



Productivity (ANPP) under the tree (red lines) and in the open grassland (blue lines). A) *P. parviflorum* and b) *A. saman*.

Conclusions

Both species of trees, *A. saman* and *P. parviflorum*, reduced grassland productivity, and the decline appears to increase with the amount of tree cover. It also appears to be related to the development of the tree crown cover (evergreen (*P. parviflorum*) or deciduous (*A. saman*)).

Productivity under the evergreen species (*P. parviflorum*) appears to follow the same temporal pattern as in the open grassland. In contrast, productivity under the *A. saman* appears to be considerably reduced at the start of the the wet season but reach the same levels of the open pasture later in the rainy season.

10 How do cattle behave with trees? Cattle activities and tree properties

This section is an extract from the MSc thesis by Anders Riis Nilsen.

Trees are common in the agricultural landscape in Central America. Some trees are commonly left when forest is cleared, and subsequently regenerate naturally, or they are planted by farmers (Harvey and Haber 1999, Harvey 2004). The most common reasons given for keeping trees in and around the pastures are shade for cattle, source of timber, fuel wood and fruit, and wind and watershed protection. Farmers in Costa Rica also claim that trees make grasses reach senescence later in dry season (Harvey and Haber 1999).

Under conditions where ambient temperature is greater than about 23º C and relative humidity is above 80%, cows of european breeds begin to suffer from heat stress (Flamenbaum *et al.* 1986). Although breeds derived from *Bos indicus* are more tolerant to heat, heat stress can lead to reduced food intake, reduced milk yield, hormonal disturbances resulting in reduced growth, reduced reproduction performance, increased respiratory rate, and increased peripheral blood flow and sweating (West 2003). Such physical and behavioural responses have a negative effect on both production and physiological status of cattle. Activity may also be lowered due to seeking of wind and shade (Gaughan *et al.* 1998, West 2003, Gallardo *et al.* 2005)

Knowledge about the spatial distribution of different cattle behavioural activities in relation to trees may help in understanding the effect of trees on pasture utilization and quality. Thus, this study focused on the following questions: i) is cattle behaviour related to the proximity to trees? ii) What effect does tree species and tree size have on the spatial behavioural pattern of cattle in relation to distance to trees? and iii) What effect does time of the day have on the spatial behavioural pattern of cattle in relation to trees?

Methods

The spatial distribution of different cattle activities was registered using the instantaneous scan-sampling technique (Altmann 1974). Each paddock was visited three times at different times of the day, morning (07-11), midday (11-14) and afternoon (14-17). All observations were made by observers moving discretely around in the paddock. Four behavioural activities were identified: feeding (F), resting (R), moving (M) and other (O). The type of activity and distance between the animal and the closest tree were recorded. The distances were measured with a laser-rangefinder (Nikon S-O Method). In addition to activity and distance, information about the tree (species, canopy diameter, height) was recorded. Any distance less than one meter was registered as one meter.

Results

Generally, cattle rested closer to trees than would be expected from a random distribution. When resting, they avoided trees in one of the paddocks and were attracted to trees in eight paddocks.

Overall, cattle fed further away from trees than would be expected from a random distribution. Out of twelve paddocks cattle showed avoidance of trees in four paddocks, and were attracted to trees in four paddocks. Also cattle discriminated between tree species when resting, and *Guazuma ulmifolia* and *Bursera simarouba* were the preferred resting trees.

In general, cattle fed at longer distances from trees than expected by random but the feeding distances from trees varied significantly between the paddocks. In some paddocks, cattle

showed avoidance of trees when feeding and in others they fed closer to trees of were indiferent to tree distance.
The distance cattle rested from trees depended on the tree species, they rested significantly closer to *Guazuma ulmifolia* and *Bursera simarouba* than to the rest of the species. There were also differences in observed feeding distances related to tree species. The cattle fed significantly closer to *Platymiscium parviflorum, Cordia allidora, Guazuma ulmifolia and Psidium guajava* than to the rest of the species and closer to *P. parviflorum* and *C. alliodora* than to *P. guajava*. The feeding distances to *Cassia grandis*, *Enterolobium cyclocarpum* and *Tabebuia rosea* were significantly lower than those to *Bursera simarouba* and *Albizia saman*.

Although cattle in this study were crossbred between zebu x european breeds, they rested closer to trees at midday than in the morning and afternoon. Generally, most resting occur at midday (usually the hottest period of the day) and in the evening (Daly 1984) and an observational study found that cattle consequently sought wooded habitat at midday and afternoon compared to the morning and evening (Zuo and Miller-Goodman 2004).

Conclusions

We found that cattle rest closer to trees and feed further away from trees than expected by random. There were different resting and feeding distances associated with different tree species. Both resting and feeding were performed closer to small trees than trees of medium and large size. Cattle rested closer to trees at midday than in the morning and afternoon. They fed closer to trees in the morning and at midday than in the afternoon.
Nevertheless, discrepancies in our results strongly indicate that there are many questions to be asked and associated relationships that need to be investigated to understand the potential trees may represent for sound pasture management in this region.

11 How are the pastures utilized? Livestock selectivity of pasture zones and plants

This chapter is an extract from the MSc theses by M Aastum and R Velásquez.

Cattle, and large herbivores in general, make decisions about where to graze at three scales, landscape, forage patch and parts of plants. The animal also makes the following four, often interdependent, decisions: 1) which patch type to visit, 2) how long to stay in each patch, 3) which food types to eat in the patch and 4) which foraging path to employ in the patch. Free-ranging animals or animals grazing in large paddocks can make choices by selecting particular plant communities or forage patches. Animals' relative preference for plant communities is generally a linear function of the relative abundance and/or nutrient quality of the preferred plants in the community, but characteristics of the species, including mouth architecture constrain selectivity.

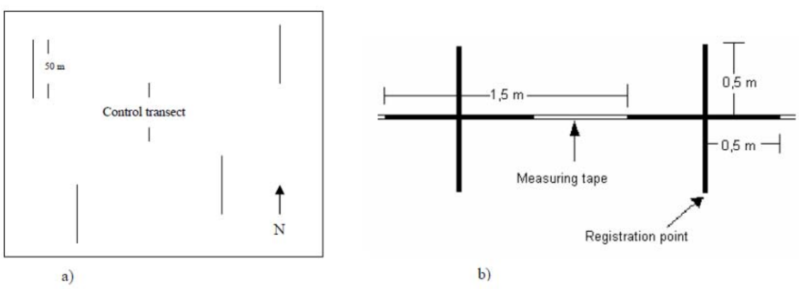
Grazing animals compose their diets by differentiating between plant species and plant parts that vary in nutritional value and in chemical and mechanical defences (Provenza and Balph 1988). Morphological characteristics, such as spines and thorns, often affect the foraging behaviour of grazing animals (Cooper and Owen-Smith 1986) as well as content of various deterring compounds (Cooper and Owen-Smith 1985). Likewise, grazing animals mainly select biomass with high proportion of leaves and low proportion of stem, as leaves have higher nutritive value. Thus, they will largely reject tall mature pastures.

Through selective grazing, cattle have the potential to change the structure and composition of the pastureland, and this is normally a result of altered interspecific plant competitive hierarchies. Knowledge about the capacity of livestock to graze selectively in relatively heterogeneous pastures is important for a better understanding of the potential to consume forage of above average value, in addition to increasing the knowledge about the possible effects of grazing on the pasture vegetation.

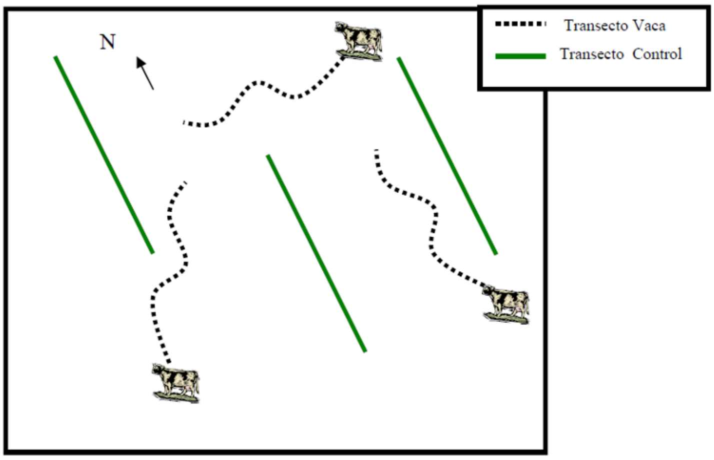
The primary objectives of the studies were (1) to determine if cattle in heterogeneous pastures are grazing selectively at different spatial scales, and (2) to find out if cattle in paddocks managed extensively and presumably with a low abundance of preferred species are less selective than in paddocks with lower grazing pressure and a high proportion of preferred species, (3) to investigate whether the decision to eat a food is independent of its abundance, but depends on the relative abundance of more preferred foods, and (4) to test if the cattle in paddocks with nutrient rich soil, where forage was assumed to be more abundant and nutrient rich, were grazing more selectively compared to the cattle grazing in paddocks with nutrient poor soil. The studies were conducted at two different periods of the year from March to August 2004 and from October 2004 to January 2005.

Methods

The vegetation of the grassland was sampled on sites of high and low fertility (as described in Chapter 6). Samples consisted on records on control transects, that characterized the vegetation available in the paddock, and on 'cow' transects indicating the trajectory of the grazing movement.



Layout of transects for the vegetation analyses in paddocks a). b) On a measuring tape a cross of stick was placed for plant interecept records which were used to estimate the total number of registrations in that transect. Source: M Aastum 2006



Location of 'cow' transects with respect to control transects in the paddocks. Source: R Velásquez 2005.

Results

Did cows graze selectively at two spatial scales?

In both the fertile and low fertility areas, the selected diet composition differed from the average species composition in the feeding sites. In the low fertility area the cows were grazing selectively at both spatial scales, whereas in the fertile area the cows did not select feeding sites of a different floristic composition than the overall paddock. The vegetation in these paddocks was in general dominated by *Panicum maximum*, which largely dominated the diet, and this species was evenly distributed within the paddocks. The paddocks in the low fertility area were in general larger, had more trees, and the soil conditions were probably more patchy in contrast to the paddocks with alluvial soils, and hence the vegetation was more diverse.

However, other factors than the abundance of preferred forage species influence on the selection of feeding sites within the paddocks. Moreover, the results indicate that the paddocks are not utilised to the greatest possible advantage as a considerably large proportion of the species are avoided and relatively few species are selected. Many of the species that were avoided were shrubs and forbs, and this implies that some of these probably should be eliminated from the paddocks.

Was the decision to eat a species dependent on the relative abundance of more preferred species?

In the fertile area only one grass species was preferred, *Panicum maximum*. However, in the low fertility area four species were preferred and the decision to eat a species depended on the relative abundance of the species in question. In the low fertility area, the proportion of the different species in the diet varied substantially among paddocks and among the individual cows.

Some species were slightly avoided by the majority of the cows, whereas one or two cows strongly preferred those species. Most of the cows had their own individual taste, and some would consume relatively large amounts of a species other cows would avoid. The fact that a food was consumed in correlation to its abundance can further enhance the differences among cows and among paddocks, as the plants of different species were unevenly distributed within the paddocks, and the species' abundance in the paddocks were dissimilar.

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