TROPICAL AGRICULTURE RESEARCH AND HIGHER EDUCATION CENTER
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TREE RESOURCES IN TRADITIONAL SILVOPASTORAL SYSTEMS AND THEIR IMPACT ON PRODUCTIVITY AND NUTRITIVE VALUE OF PASTURES IN THE DRY TROPICS OF COSTA RICA

By

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DEDICATION

I dedicate this dissertation to:

My family

Virginia, my wife, friend and partner for her teachings, help and support during this difficult part of our lives and together with whom, after all we have been through, I hope to spend the rest of my life.

and

especially to

My lovely children Humberto and Marcela for all the time that we had to spend apart from each other and from whom it is not fair to change their entire lives for one bad day but, for whom I will like to forget one bad day from my entire life.

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ABREVATIONS INDEX

n	number of observations
g	grams
l	liters
m	meters
m^2	square meters
cm	centimeters
kg	kilograms
km^2	square kilometers
º C	Celsius
na	not available
ha	hectare
dbh	diameter at breast height
spp	species
UK	United Kingdom
US	United States of America
CC	crown cover
TD	tree density
LU	livestock units
SR	stocking rate
ME	metabolizable energy
CP	crude protein
DM	dry matter
NDF	neutral detergent fiber
Mcal	megacalories
MVZ	Medico veterinario zootecnista
PAR	photosynthetically active radiation
LAI	leaf area index
MPT	multipurpose trees
MAG	Ministerio de Agricultura y Ganadería
SHB	standing herbage biomass
PSHB	paddock standing herbage biomass
IVDMD	*In vitro* dry matter digestibility
UADY	Universidad Autónoma de Yucatán
FMVZ	Facultad de Medicina Veterinaria y Zootecnia
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza
ANOVA	analysis of variance

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Key words: Abundance, Agroforestry systems, Animal nutrition, Biodiversity, *Brachiaria brizantha*, Dispersed trees, Dry forest, Richness, Shading, Sustainability, Tree cover.

Abstract

Maintaining or increasing the number of scattered dispersed trees in pastures represents an important option to improve productivity and sustainability of cattle farm systems in the dry tropics, particularly during prolonged dry periods, when trees provide fodder of high nutritional quality in addition to their ecological and social value. However, little is known about presence, structure and characteristics of dispersed tree in pastures of cattle farms, how they are related to different cattle farm systems, and what effects they have on cattle farm productivity.

This study characterizes and describes the cover of dispersed trees in pastures and explores the different effects that dispersed trees in pastures have on cattle farm productivity in a tropical dry ecosystem in Costa Rica during 2002-2003. The general objective of the study was to provide information about the tree cover (percentage, arrangement, composition and density) dispersed in pastures, relate patterns of tree cover to different cattle farms based on size (small, medium and large) and production system (beef or agriculture + beef farms) and explore how tree cover influences total fodder (grass and pods) availability and quality.

In the characterization study, a total of 5,896 dispersed trees belonging to 99 species of 36 families were counted. Trees were present on 100 % of the farms and in 170 (85 %) of the paddocks inventoried. The most abundant families were *Bignonaceae*, *Sterculeaceae*, *Boraginaceae*, *Arecaceae*, and *Papilionaceae*; whereas the most common tree species were *Tabebuia rosea*, *Guazuma ulmifolia*, *Cordia alliodora* and *Acrocomia aculeata* which together accounted for 60 % of the total trees. Dispersed trees in pastures were present as individual trees (54 %) and in clusters (trees in groups; 46 %), but no differences were observed across farm types. Crown cover (m^2 ha^{-1}) and tree density (individuals ha^{-1}) were significantly different ($P < 0.05$) across farm types with higher values found in small beef cattle farms. No significant differences ($P > 0.05$) were found for Shannon and Simpson diversity indices among the farm types studied, due to the similar management practices and site conditions across farm types.

There was a positive significant ($P < 0.05$) quadratic relationship ($r^2 > 0.70$) between % tree crown cover and paddock standing herbage biomass for early and late dry season. This result is attributable to the beneficial positive effects that tress have on pastures.

During the early rainy season, a similar trend was found but the results were not significant ($P > 0.05$). On an individual tree basis, standing herbage biomass under the crowns of mature tree species was significantly ($P = 0.006$) lower (12 – 72%) compared to that outside tree canopy but with differences among tree species. Guanacaste (*Enterolobium cyclocarpum*) and guacimo (*Guazuma ulmifolia*) tree crowns intercepted a higher proportion of the incoming PAR (77 % and 68 % respectively) compared to other species. Due to this, standing herbage biomass under the crowns of these two species was significantly ($P < 0.05$) lower than under the other tree species.

The area beneath Guanacaste and guacimo canopies was dominated by broad-leaved weeds (*Richardia* spp, *Triunfetta semitriloba*) whereas *B. brizantha* dominated under the other tree species. The herbage biomass crude protein content (CP) was higher under tree canopies than in open areas. *In vitro* dry matter digestibility (IVDMD) varied between species. Standing herbage biomass under the crown of the leguminous trees, Guanacaste and genizaro (*Samanea saman*), had higher CP content than under other tree species. Significant differences were also found in standing herbage biomass and quality across seasons due to lack of rains and higher grass maturity rates during the dry season.

Total and weekly fresh fruit production (kg tree^{-1}) of Guanacaste trees (37.6 and 9.6 kg tree^{-1}, respectively) was significantly higher ($P < 0.05$) than that of other species. The crude protein content of fruits from this species and genizaro as well, were significantly higher ($P < 0.05$) than those of the non-leguminous trees, coyol (*Acrocomia aculeata*) and guacimo, but in general genizaro fruits had better nutritive quality. Coyol was the tree species with lowest total fresh fruit production (mean of 7.2 kg tree^{-1}) and produced fruit of lower nutritional quality. Fruits distribution along the dry season from different species with different nutrient quality provides a stable diet to cattle during the dry seasons.

Simulation of different combinations between cover percentages and species composition of dispersed trees in pastures showed that increasing crown cover (CC) in pastures from low (10 %) to very high (50 %) reduces *B. brizantha* grass dry matter (kg DM ha^{-1}) from 2.7 up to 51.3% relative to that produced in pasture plots without tree cover (BLS), but the effect of the CC depended on tree species composition. Higher grass DM reductions were observed in the dense silvopastoral scenarios (SPS) which include large and dense tree species such as guacimo and Guanacaste. Increasing tree cover contributes to higher fruit production but the contribution of fruits to total fodder dry matter depended on tree species composition of pasture plots being highest in the dense, mixed and fruit SPS. Fruits, Mixed and Moderate SPS simulated had higher total fodder crude protein (kg CP ha^{-1}) whereas all SPS had lower total fodder metabolizable energy (Mcal ha^{-1}) compared with the BLS. Beef cattle grazing SPS gained higher live weight changes (40 -45 g day^{-1} animal^{-1}) compared to those grazing at the BLS being highest for the Moderate SPS. Simulations performed suggest that increasing CC of pasture plots to moderate (<30%) percentages including fruits bearing tree species producing fruits of higher nutritional quality than pastures can improves cattle productivity by the provision of additional fodder compensating the grass losses caused by trees.

It is concluded that farmers are managing a wide diversity of dispersed trees in pastures but at low densities and cover percentages (< 15 %) with the objective of fulfilling different farm needs minimizing pasture reduction. Dispersed trees in pastures provide additional fodder (fruits) of higher nutritional quality than grasses during the dry season which in consequence increased cattle live weight changes. Both the simulation and the low crown cover found in cattle farm systems yet far from being definitive, suggest that farmers can increase tree cover of pasture plots up to moderate levels (30 % crown cover). This should include a mixture of multipurpose tree species composition which will contribute to improve both cattle and farm productivity.

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Palabras clave: Sistemas silvopastoriles, trópico seco, biodiversidad, cobertura arbórea, abundancia, riqueza, nutrición animal, sombra, *Brachiaria brizantha*.

Resumen

El mantener o incrementar la presencia de árboles disperses en potreros representa una importante opción para mejorar la productividad y sostenibilidad de las fincas ganaderas en el trópico seco, particularmente durante prolongados periodos secos donde los árboles proporcionan forraje de mayor calidad nutricional aparte del beneficio social y ecológico que proporcionan a las fincas. Sin embargo, muy poco se sabe acerca de la presencia, estructura y características de las especies arbóreas dispersas en las pasturas de las fincas ganaderas, de como esto se relacionad con los diferentes sistemas ganaderos y de cuales son los diferentes efectos que los árboles dispersos ejercen en la productividad de las fincas ganaderas.

Este estudio caracteriza y describe la cobertura de árboles dispersos en los potreros y explora los diferentes efectos que ellos tienen sobre la productividad de fincas ganaderas en un ecosistema del trópico seco de Costa Rica durante el 2002 – 2003. El objetivo general del estudio fue proporcionar información sobre la cobertura arbórea (porcentaje, arreglos, estructura, composición y densidad) de los arboles dispersos en las pasturas, relacionarlos con la diferentes tipos de fincas (ganado de carne y agricultura mas ganado de carne) y explorar como influencia la disponibilidad y calidad del forraje (pastor y frutos) disponible para el ganado.

En el estudio de la caracterización arbórea, se encontró un total de 5,896 árboles pertenecientes a 99 especies y 36 familias. Se encontraron árboles en el 100% de las fincas y en 170 (85%) potreros. Las familias de árboles mas abundantes fueron *Bignonaceae*, *Sterculeacea*, *Boraginaceae*, *Arecaceae*, y *Papilionaceae*, mientras que las especies mas comunes fueron *Tabebuia rosea*, *Guazuma ulmifolia*, *Cordia alliodora* y *Acrocomia aculeata* quienes conforman el 60% de todos los árboles inventariados. Los arreglos de árboles dispersos en las pasturas se encuentran presentes como árboles aislados (54%) y formando grupos (46%), pero no se encontraron diferencias significativas entre los diferentes sistemas de producción. Sin embargo, si existieron diferencias significativas ($P < 0.04$) entre los sistemas de producción para la cobertura arbórea (m^2 ha^{-1}) y la densidad (árboles ha^{-1}) en donde el sistema ganadero pequeño de carne tuvo mayor cobertura y densidad que en los otros sistemas. No se encontraron diferencias significativas ($P > 0.05$) entre los sistemas de producción para los índices de diversidad de Shannon y Simpson debido al similar manejo y condiciones de las pasturas.

El análisis de regresión entre la cobertura de árboles dispersos en potreros mostró un efecto cuadrático positivo ($r^2 > 0.70$) sobre la disponibilidad de biomasa forrajera de los potreros para la época de sequía ($P < 0.05$). Este resultado puede ser atribuido al efecto benéfico que ejercen los árboles sobre las pasturas. Sin embargo, durante la época de lluvia, aunque se encontró un patrón similar los resultados no fueron significativos a $P > 0.05$. Por el contrario, debajo de la copa de todas las especies estudiadas, los árboles disminuyeron significativamente ($P = 0.006$) entre un (12 – 72 %) la disponibilidad de biomasa comparado con la obtenida a pleno sol. Las copas de los árboles de Guanacaste (*Enterolobium cyclocarpum*) y guacimo (*Guazuma ulmifolia*) fueron las que interceptaron mayor proporción de la luz solar RAFA (77 % y 68 % respectivamente) comparada con las copas de las otras especies. Debido a esto, la disponibilidad de biomasa debajo de las copas de estas dos especies arbóreas fue significativamente menor ($P < 0.05$) comparada con las otras especies arbóreas.

El área abajo de la copa de estas mismas dos especies fue dominada por malezas de hoja ancha (*Richardias* spp, *Triunfetta semitriloba*) mientras que el área debajo de la copa de las otras especies fue dominada por pasto de la especie *Brachiaria brizantha*. El contenido de proteína cruda (CP) fue significativamente ($P < 0.05$) mayor bajo la copa de todas las especies arbóreas que a pleno sol, mientras que la digestibilidad *in vitro* de materia seca (IVDMD) vario entre especies. El contenido de CP de la biomasa debajo de la copa de los árboles leguminosos Guanacaste y genizaro (*Samanea saman*) fue mayor que el de los árboles no leguminosos. Al igual que en las especies, se observaron diferencias significativas ($P<0.05$) para la disponibilidad y calidad de la biomasa forrajera entre épocas causada principalmente por la falta de lluvias y la madurez del pasto.

La producción total y semanal de frutos frescos (kg $árbol^{-1}$) de Guanacaste (37.6 y 9.6 kg $árbol^{-1}$, respectivamente) fueron significativamente superiores ($P<0.05$) a la producción de las otras especies. El porcentaje de proteína cruda de los frutos de esta especies junto con el genizaro fue significativamente superior ($P < 0.05$) al de las especies no-leguminosas coyol (*Acrocomia aculeata*) y guacimo; pero en general los frutos de genizaro tuvieron la mejor calidad nutricional. Por el contrario, árboles de coyol produjeron la menor cantidad de frutos (promedio de 7.2 kg $árbol^{-1}$) y fueron también los de menor calidad nutricional. La distribución de frutos de diferente calidad nutritiva en las pasturas proporciona al ganado una dieta más estable durante la época de sequía.

Simulaciones de las combinaciones de especies arbóreas con diferentes porcentajes de cobertura arbórea mostraron que incrementar la cobertura arbórea de los potreros de baja (10%) a muy alta (50%) reduce la producción de materia seca de pasto *B. brizantha* se entre 2.7 y un 51.3% en relación a la producida en un potrero sin árboles (SB), pero esta disminución depende de la composición de especies arbóreas del potrero. Se observaron mayores reducciones de pasto en el escenario denso el cual incluyó especies de copas grandes y densas como los árboles de guacimo y guanacaste. Incrementar la cobertura arbórea contribuyó con una mayor producción de frutos, pero la contribución de los al total del forraje disponible para los animales donde de la composición de especies arbóreas presentes en el potrero siendo mayor en los escenarios, mixto, frutos y denso. Los escenarios silvopastoriles mixto, frutos y moderado tuvieron una mayor producción de proteína cruda (kg CP ha^{-1}) comparada con el escenario base, mientras que todos los escenarios silvopastoriles tuvieron menor energía metabolizable (Mcal ha^{-1}) disponible. Simulaciones de novillos pastoreando en el escenario silvopastoril moderado tuvieron las mayores ganancias de peso (entre 40 y 45 g $animal^{-1}$ $día^{-1}$) comparado con los otros escenarios, aunque todos los novillos pastoreando en los escenarios silvopastoriles ganaron mas peso (entre 40 y 45 g $animal^{-1}$ $día^{-1}$) que los novillos pastoreando en el escenario base. Las simulaciones realizadas sugieren que incrementar la cobertura arbórea de los potreros hasta niveles moderados (<30%) incluyendo especies arbóreas que produzcan frutos de una mayor calidad nutritiva que los pastos mejora la productividad de los novillos mediante la provisión de alimento adicional con una mayor calidad nutritiva que compensa la disminución de la producción de pasto causada por los árboles.

Se concluye que los productores mantienen una amplia diversidad de árboles dispersos en los potreros pero a bajas densidades y porcentajes de coberturas con el objetivo de cubrir diferentes necesidades y evitar reducciones en la producción de la pastura. Los árboles dispersos en las pasturas proporcionan frutos de mayor calidad nutritiva que los pastos proporcionando alimento adicional para el ganado durante la época de sequía lo que repercute en mayores ganancias de peso. Aunque tanto las simulaciones realizadas como la baja cobertura arbórea encontrada en las fincas ganaderas distan mucho de ser definitivos, sugieren que los productores pueden aumentar la cobertura arbórea de los potreros hasta niveles moderados (20-30%). Esto debe de incluir la mezcla de especies arbóreas multipropósito lo que contribuiría a mejorar tanto la productividad del ganado como de la finca.

BIOGRAPHY

Mr. Humberto Esquivel Mimenza was born in Mérida, Yucatán México on December 11, 1962. He spent his childhood in his natal city where he concluded his elementary and bachelor studies at the Centro Universitario Montejo. In 1986 he obtained a professional degree in Animal Husbandry at the Technological Institute of Monterrey (ITESM) in Monterrey, N.L (Mexico). In 1989 he obtained a Masters degree in Tropical Animal Production at the University of Reading, England. He works as a research professor in Animal Production and Husbandry mainly with sheep and cattle at the Faculty of Veterinary Medicine and Animal Husbandry of the Autonomous University of Yucatan since 1986. He enrolled in CATIE´s PhD. Program in September, 2000.

CHAPTER I

GENERAL INTRODUCTION

Introduction

Extensive livestock production systems have been established in large areas of land where the original forest has been cleared and converted to grass monocultures to feed cattle. This process, largely encouraged by policy makers, takes place immediately after clearing the forest in a slash-and-burn system or most commonly after two to three years of shifting cultivation with crops such as maize (*Zea mayz*) and beans (*Phaseolus vulgaris*), followed by planting with grasses (Ibrahim *et al*. 2000; Muchagata and Brown 2003; FAO 2005). However, while large areas have been cleared to serve this purpose, forest clearing has been harmful to the environment causing deforestation, soil erosion, land fragmentation, desertification, pasture degradation with consequent environmental damage, global warming through the production of green house gases and loss of biodiversity (Kaimowitz 1996; Timon 2004; FAO 2005). The benefits of the conversion of tropical forest to native or naturalized pasture monocultures have been proven to be temporary due to the rapid depletion of soil nutrient reserves from original forest soils which can not maintain pasture productivity for long. Thus, as soon as soil fertility is depleted, pasture productivity falls forcing farmers leave in fallows land and to expand further into forest lands to substitute new land for the decline in productivity.

To address this problem, in the past two decades large areas of naturalized degraded pastures in the seasonally dry areas in Central America were converted to improved pastures with species (mainly of the *Brachiaria* genus) that are more productive and drought tolerant than native and naturalized pastures (Wong 1990; Bhatt *et al.* 2002; Carvalho *et al.* 2002). However, the benefit from the introduction of these more productive forages has only solved temporarily the problem. Cattle farmers frequently experience a sharp decline in pasture and animal productivity (>50%) within five years of pasture establishment. This is caused mainly due to the fact that the more productive grass species require higher nutrient levels (i.e. fertilization) than naturalized grasses, which are not usually provided by most farmers and to inadequate grazing practices and overgrazing, leading to pasture degradation.

Nowadays, more than 50% of Central American pastures are estimated to be degraded or are in the process of degradation (Szott *et al.* 2000). This implies that converting naturalized pastures to improved grass species has contributed little to improve farm productivity in such a way that cattle performance based mainly on extensive grazing from tropical pastures as a principal feed source has been proven to be low. Cattle performance heavily depends on the nutrient quality (crude protein and energy) and digestibility of forages. However, most tropical forages are not sufficiently digestible or nutritious to meet all the animal's nutritional requirements, especially in the dry and semi dry tropical areas where there is high degree of incompatibility between seasonal forage production and livestock nutritional requirements due to seasonality in pasture production pattern from these areas. In the rainy season, pasture production exceeds intake capacity of cattle and there is a large proportion wasted and recycled as residual material. On the contrary, during the dry season, when long seasonal dry periods (120 to 180 days year^{-1}) and frequent droughts occur (Shelton 2004), pasture production is limited by lack of moisture and pastures have poor digestibility (< 38%) and crude protein content (< 7%) to meet cattle nutritional requirements (Minson 1990). This consequently causes low growing rates ($\pm$ 250 g animal^{-1} day^{-1}), heavy weight losses, low milk production yields ($\pm$ 3.5 l cow^{-1} day^{-1}), long calving intervals (> 400 d), poor reproductive performance and in extreme cases, cattle mortality (FAO, 2000; Shelton 2004; FAO 2005). Therefore, opportunities for improving livestock productivity in these areas need to be directed towards mitigating the "normal" forage deficit. The inclusion of multipurpose tree species in pastures has the potential to provide additional fodder of higher nutritional quality than grasses apart from providing shade and shelter to cattle. Trees also contribute to mitigate the adverse environmental conditions inside the system reducing air temperatures and wind speed favoring pasture production. Another aspect associated with the presence of trees in pastures is the improvements in soil fertility and reductions in soil erosion.

In the same way, supplementary feeding (providing additional protein and energy supplement to cattle) has proven to increase livestock production, when animals are fed with low quality forage diets. Thus, the use of grains such as sorghum and maize, commercial concentrates and agriculture byproducts like chicken manure is a generalized practice among farmers to increase cattle production raised on low forage diets (Preston and Leng 1990; Ibrahim *et al.* 2001). However, the recent appearance of cattle diseases (i.e. Bovine Spongiform Encephalopathy) caused by feeding animal byproducts to cattle and the high prices of the imported supplements and concentrates have made these practices less economical feasible (Szott *et al*. 2000; Rueda *et al*. 2003). This situation has forced farmers to look for other supplementary alternatives to maintain cattle productivity.

Agroforestry practices, particularly silvopastoral systems are an alterantive land use type to reduce deforestation, reduce the "normal" forage deficits and provide additional higher nutrient quality fodder in order to increase livestock productivity. Silvopastoral systems combine the use of multipurpose trees and shrubs integrated with pasture and cattle and other livestock (Nair 1989). Several silvopastoral systems are used in the tropics, (Murgueito 1999; Pezo and Ibrahim 1999; Sanchez 1999; Galindo *et al.* 2003), one of which is the maintenance of dispersed trees in pastures. This type of system can be defined as one where multi-species trees are found in a non systematic arrangement (either isolated or in clusters) within the pastures. The trees were either left behind after the establishment of the pastures through a slash-and-burn process, arose from natural regeneration or, less commonly, were planted by farmers. From an environmental viewpoint, trees can serve as stepping stones for animals (Snelder 2001), while at the same time, enhancing landscape connectivity and aesthetics, providing environmental services (i.e. carbon sequestration) and protecting watershed and conserving biodiversity (Guevara *et al*. 1998; Harvey and Haber 1999; Pagiola *et al*. 2004; Harvey *et al.* 2005). As such, there are many benefits that may be obtained from tree cover maintained in cattle farm systems.

Maintaining or even increasing dispersed trees in the pastures in the dry tropics or in areas that receive prolonged dry periods, represents an option to increase the productivity, profitability and sustainability of cattle farm systems (Pezo *et al*. 1999; Szotts *et al*. 2000; Galindo *et al*. 2003; Devendra *et al*. 2004; Kallenbach *et al*. 2006). Many authors have shown that trees provide benefits to cattle farms and the environment (Harvey and Haber 1999; Aguilar and Condit 2001; Gibbons and Boak 2002; Teklehaimanot *et al.* 2002). Trees can provide farmers with additional non - cattle products like timber, fence posts, firewood and fruits as a means to minimize risk and diversify production to obtain economic benefits (Beer *et al*. 2000; Gibbons and Boak 2002; Devendra and Ibrahim 2004). Trees can also be an important source of shade and shelter to cattle. Shade trees have been shown to significantly improve animal productivity by reducing heat stress in tropical climates. Milk cows grazed in shaded pastures showed an increase between 9% and 29% in milk production in comparison to milk cows grazed in un-shaded pastures (Souza de Abreu *et al*. 1999) and in low (crown cover < 10%) shaded pastures (Betancourt *et al*. 2003). Similarly beef cattle live weight gains were higher in Zebu cattle grazing in moderate shaded paddocks in comparison to cattle grazing in low or high shaded paddocks (Restrepo *et al*. 2004).

In addition, some tree species produce leaves and pods which are highly palatable to cattle and are available during the dry season when pastures are of low nutritional quality. Feeding cattle with leaves and pods from trees improves cattle productivity (live weight gain and milk production). The products from these trees that can be consumed by cattle are characterized as having higher nutritional quality (CP > 12% and IVDMD > 65%), particularly leguminous species, than the associated grass species (Ortega *et al*. 1998; Solorio *et al*. 2000; Aguilar and Condit 2001; Alvarez *et al*. 2003; Ku 2005). Fruits of the multipurpose tree species such as *Guazuma ulmifolia* (guacimo), *Phitecellobium saman* (genizaro), *Enterolobium cyclocarpum* (Guanacaste) among others, have been used to feed livestock, substituting grain feed and improving livestock productivity particularly during the dry season (Moscoso *et al.* 1995; Ortega *et al.* 1998; Durr 2001; Zamora *et al.* 2001). Studies in México showed that replacing corn grain and soybean rations with flour from *Enterolobium cyclocarpum* seed pods, sheep maintained similar live weight gains

(150 g) to animals fed with grain-based rations but with a significant reduction in costs (Alvarez *et al.* 2003; Peralta *et al.* 2004). In the same way, when fruits of *Guazuma ulmifolia* were fed to sheep consuming poor quality forage diets, dry matter intakes increased up to 30 % compared to sheep fed with poor quality forage diets only (Perez *et al.* 2005). It also has been reported that livestock fed with fruits of multipurpose tree species (MPT) increased their live weight gains compared to livestock fed only with grasses. Steers consuming *Pithecellobium saman* fruits gained more live weight (500 g day^{-1}) compared to the steers without supplementation (400 g day^{-1}). Similarly, milking cows fed with fruits of the same tree specie at levels of 15 % of their intake capacity increased milk production by 2.2 l cow^{-1} day^{-1} (Roncallo *et al.* 1996; Baquero *et al.* 1999).

Fortunately, most farmers maintain dispersed trees in their pastures (Guevara *et al*. 1998; Harvey and Haber 1999; Villanueva *et al.* 2003; Esquivel *et al.* 2003; Harvey *et al.* 2005) which represent an excellent means to increase fodder and protein source to cattle. However, despite the large number of trees than can be seen at landscape levels, most of the research on traditional silvopastoral systems in the dry and semidry tropics has focused on the comparison of forage growing under shade of individual tree species with that growing at full sun light (Belsky *et al*. 1989; Belsky *et al*. 1993a; Belsky *et al*. 1993b; East and Felker 1993; Durr and Rangel 2000). Other studies have focused on the nutritional value of forage from native trees and shrubs for feeding cattle, especially during the dry season (Topps 1992; Solorio *et al*. 2000) while other studies have focused on how tree cover affects pasture and animal productivity in silvopastoral systems where trees are arranged systematically (i.e forest/fruit plantations; Sibbald *et al*. 1991; Fernandez *et al*. 2002). While these studies provide a solid basis for the use of trees and shrubs in cattle farm enterprises at individual levels, there is limited information about how richness, abundance, distribution, density and cover of tree species occurs in pastures of cattle farms. Even less information is available on how these tree cover varies across farm types, what factors contribute to patterns of tree species distribution within the pastures and how this tree cover affects standing herbage biomass of pastures, and how fruits from these tree species produced during the dry season contributes towards mitigating cattle fodder deficit.

In order to help farmers to make better decisions regarding tree cover and species composition of pastures and to improve animal productivity it is necessary to provide information about what the patterns, structure and composition of tree resources in pastures are; how it varies across the landscape and across different cattle farms systems; what are the trade-offs between tree cover and pasture production and how trees contribute to cattle production by the provision of fruits of higher nutritional quality than pastures during the dry season. This information will also allow for designing incentives schemes by policy makers and creating policies that promotes tree planting and conservation of tree resource in cattle farm systems.

Objectives and Hypothesis

General objective

To provide information about the tree cover (pattern, arrangement, composition, density, abundance) dispersed in pastures, relate tree cover to cattle farms of different types and explore how tree cover influences the availability and the nutritional quality of the overall fodder (grass and tree pods) at both the individual tree level as well as at pasture level in such a way that provides information for a better design of silvopastoral systems.

Specific Objectives

1. To characterize dispersed trees in pastures of cattle farms and compare tree cover among different farm types

2. To evaluate the effect of different tree cover on the standing herbage biomass availability and botanical composition of *Brachiaria brizantha* pastures

3. To evaluate the effect of the most common individual tree species dispersed in pastures on the availability, nutritive quality and botanical composition of the standing herbage biomass growing under their canopies

4. To estimate the production and quality of fruits from the most commonly fruit-bearing tree species used to feed cattle in the study zone

5. To explore, by means of computer simulation modeling, how dispersed tree cover in pastures is related to fodder availability and animal performance

Hypothesis

The cover and arrangement of trees on livestock farms is related to farm type and management system

- Pasture availability in the dry and semi dry tropics can be favored by the dispersed tree cover in pastures that can protect grass from the adverse environmental condition.

- Pasture availability, nutritional quality and botanical composition underneath tree canopy is influenced by tree species

- There is a relationship between livestock productivity and cover and composition of dispersed trees in pastures.

Approach of the study

These research gaps will be encompassed by three major components that were combined to address the research objectives proposed. The first component (Paper 1) involved a field survey characterizing the tree cover dispersed in pastures and relating tree cover to different type of beef cattle farms. The second component was comprised of experiments and monitoring in traditional silvopastoral field trials to evaluate the effects of tree cover on grass productivity at both the individual tree level as well as at pasture level. Fruit production from the main fruit bearing tree species that are used to feed cattle in the study zone was also measured (Paper II). Finally, a third paper consist of a simulation model that explores the effects of increasing tree cover (10 – 50%) in pasture plots with different tree species composition on total fodder (grass and fruits) dry matter and the nutritive quality of the fodder available to cattle in the silvopastoral system of a dry tropical ecosystem in Guanacaste, Costa Rica. The following table (Table 1) synthesizes the objectives, methodologies and activities undertaken during the research to show how the three studies related each other.

Table 1. Description of the objective, methods and activities conducted during the studies.

Objective	Methodology	Activities
To characterize dispersed trees in pastures of cattle farms and compare tree cover among different farm types	Tree census	Identify, inventory and measure all trees > 10 cm in dbh dispersed in pastures of cattle farm systems. Calculate tree cover percent of each pasture plot Calculate diversity and similarity indices among different cattle farms.

To evaluate the effect of different tree cover on the standing herbage biomass availability and botanical composition of *Brachiaria brizantha* pastures	Field experiments at pasture level Botanal technique	Select pasture plots with different tree cover percentages Measure standing herbage biomass and botanical composition at pasture level at three contrasting periods
To evaluate the effect of the most common individual tree species dispersed in pastures on the availability, nutritive quality and botanical composition of the standing herbage biomass growing underneath tree canopies	Field experiments at individual tree level Pasture sampling Pasture nutritive quality laboratory analysis	Select the most common tree species disperses in pastures of cattle farms Measure standing herbage biomass growing underneath tree canopies and compare them with that produced at the full sunlight areas. Estimate nutritional quality of pasture at both full sunlight areas and underneath tree canopies
To estimate the production and quality of fruits from the most commonly fruit-bearing tree species used to feed cattle in the study zone	Direct fruit collection Fruit nutritional quality laboratory analysis.	Fruit fall collection and nutritive value laboratory analysis of fruit samples assessed weekly.
To explore, by means of computer simulation modeling how dispersed tree cover in pastures is	Simulation modeling	Construct a static simulation model that is able to estimate total fodder (grass and fruits)

related to cattle fodder availability.		availability to cattle based on different tree cover percent and tree species composition of pastures.

CHAPTER II

LITERATURE REVIEW

Silvopastoral systems

When trees, shrubs, pastures and animals interact with each other in the same land unit and under an integral management, the system is denominated as a silvopastoral system (Nair 1989; Pezo and Ibrahim 1999; Sanchez 1999). However, the system components (trees, pastures and animals) can be combined in very diverse arrays generating different types of silvopastoral systems including forage banks, alley farming, fruit and forest plantation combined with animals, live fences, windbreaks and dispersed trees in pastures (Pezo and Ibrahim 1999; Galindo *et al*. 2003).

Forage banks

This is a system in which woody perennial plants or herbaceous forage plants are grown in compact blocks with a high tree density with the objective of maximizing forage production of a high nutritive value. There are two types of forage banks, protein banks if forages contain higher crude protein (> 15%) and energy banks, if the plants are high on energetic content (Pezo and Ibrahim 1999; Camargo *et al*. 2000; Calle *et al*. 2001).

Alley farming

This silvopastoral system is similar to that of alley cropping but grasses are planted between tree rows instead of crops. The main objective of this system is to increase cattle productivity with forage production all year round and increase soil quality (Pezo and Ibrahim 1999).

Timber/fruit plantations

Grazing under timber and fruits plantations is a common practice in a number of countries. There are two main variations of this system, cattle as a complement to forestry/fruit plantation or forest/fruit plantation as a complement to livestock production. In the first variation cattle are complementary to the main system component (forest/fruit) and they serve as weed regulators or as an additional source of income while the plantation becomes productive. In the second type cattle are the main system component and trees are planted to diversify farm income (Chin 1993).

Lives fences

This system, together with dispersed trees in pastures is one of the most common silvopastoral systems found in all Central America (Camargo *et al*. 2000; Galindo *et al*. 2003). Live fences are mainly used to delineate pasture or farm borders and consist of the plantation of woody perennial trees as poles. This system has shown its economic (54 % cheaper with respect to conventional fences) and ecological importance by reducing the pressure for acquiring biodiversity corridor, firewood and poles from forest (Pezo and Ibrahim 1999; Calle *et al*. 2001).

Dispersed trees in pastures

Complete deforestation for farming establishment hardly ever occurs. Farmers tend to leave scattered trees during the slash-and-burn process to serve different functions in the farm (Muchagata and Brown 2003), resulting in a mosaic of pasture and agricultural field patches with scattered dispersed trees within them.

Dispersed trees in pastures can be defined as pastures where multi-strata, multi-purpose tree species are found in a non-systematic arrangement either as isolated trees or in clusters within the pastures. These trees may be left by farmers, arose from natural regeneration or (less commonly) were planted by farmers.

Importance of dispersed trees in pastures

Livestock production systems are based mainly on the extensive grazing of monoculture pastures as a principal source of feed to cattle. However, under these farming systems which were developed for temperate areas, livestock productivity has been generally low among most cattle farms (FAO 2000; Shelton 2004). This poor cattle performance is mainly due to the lack of constant forage and food supply of high nutritional quality caused by the seasonal dry periods (120 to 180 days year^{-1}) and frequent droughts (Shelton 2004). A consequence, grass have high fiber and low quality diets and cattle usually do not meet their nutritional requirements (Minson 1990; Hens and Lazcano 1994) and have low production levels (body weight, milk production and reproduction rates).

Generally livestock farms in the American tropics have been established at the expense of forest clearing. Oftentimes, farmers have been accused of causing deforestation, desertification and pollution and contributing to global warming through the production of greenhouse gases (FAO 2005). Additionally, the frequent use of fire to control weeds and inadequate pasture management and livestock stocking rates have widely exposed pastures and soil, causing degradation and the consequent loss of productivity (FAO 2000; Sottz *et al*. 2000; McIvor 2002).

Trees increase nutrient cycling, improve soil physical and chemical properties, reduce erosion rates and modify microenvironmental conditions improving pasture productivity (Belsky *et al*. 1989; Belsky *et al*. 1993b; Wilson and Ludlow 1991; Linn *et al*. 2001; Gibbons and Boak 2002; Power *et al*. 2003). They provide shade, shelter and dry season fodder to cattle reducing the dependency on external inputs (MacDickens and Vergara 1990; Zamora *et al*. 1999; Souza de Abreu 2002; Betancourt *et al*. 2003). Trees also provide farms with additional income apart from cattle, intensifying diversification through different sources of products without a detrimental effect on farm productivity (Beer *et al*. 2000). Therefore, the use of multipurpose trees dispersed in pastures could have a greater potential to overcome cattle farm problems through the beneficial contribution of trees provide to animals and to the farms. Trees can provide fruits and forage of higher nutritional quality than pastures while at the same time favor environmental conservation thought improving soil fertility and avoiding soil and biodiversity loss. .

Characterization of dispersed trees in pastures

It is common to find scattered dispersed trees in pasturelands of Central American cattle farms. They generally occur in small groups, in lines and randomly dispersed (Villafuerte 1998; Kleinn 1999; Sinclair 1999). However, farmers greatly influence tree cover by favoring the species that they prefer (Muñoz *et al*. 2003). Different efforts have been conducted in American tropics to inventory and characterize the tree component present in pasturelands with regard to farm type (dairy, mixed or double purpose; Souza de Abreu *et al.* 2000), size (small, medium, large; Viera and Barrios 1998) and location (humid and dry areas; Harvey and Haber 1999; Casasola 2000; Morales and Kleinn 2001). In a recent study, Morales (2000) found 60 tree species dispersed in 157 ha of pasture in the northwestern province of Guanacaste. In the same province, Stokes (2001) found that farmers listed 72 tree species growing in the pastures of their farms. In another study carried out on remnant trees in pastures (237 ha) of dairy farms in the Monteverde region of Costa Rica, Harvey and Haber (1999) found 190 species (5,583 trees). Of these species, 37 % were classified as timber species. Souza de Abreu *et al*. (2000) reported between 73 and 88 % of tree species in silvopastoral systems in San Carlos, Costa Rica were timber tree species. In an inventory of dispersed trees in paddocks of Mexican farms, Guevara *et al*. (1998) found 98 tree species of which 76 species (77.5%) correspond to primary forest species. Similarly, in the Northern region of Costa Rica, Van Leeuwen and Hofslede (1995) found that 96.2 % out of 79 tree species corresponded to primary forest species. The main tree species found dispersed in these studies included timber trees, such as laurel (*Cordia alliodora*), roble (*Tabebuia rosea*), cedro (*Cedrela odorata*), gavilán (*Pentaclethra macroloba*), jául (*Alnus acuminata*) and ciprés (*Cupressus lusitanica*). They also include fruit trees such as, guayaba (*Psidium guayaba*), limón dulce (*Citrus limeta*), naranjo dulce (*Citrus sinensis*), mango (*Mangifera indica*) and guava (*Inga sp*). Multipurpose tree species were also represented mainly by Guacimo (*Guazuma ulmifolia*), Guanacaste (*Enterolobium cyclocarpum*), Ramón *(Brosimum alicastrum*), genizaro (*Samanea saman*) and carbón (*Accacia pennatula*) (Viera and Barrios, 1998; Harvey and Haber 1999; Casasola 2000; Souza de Abreu *et al.* 2000; Morales and Kleinn 2001; Stokes 2001). These studies have also shown that tree cover is heterogeneous with respect to density, species composition and percentage of area covered.

Interactions in silvopastoral systems

The relationships between the components (animals, pastures and trees) of silvopastoral systems involve both positive and negative interactions which may occur simultaneously (Holmgren *et al*. 1997). Therefore, it is important to distinguish the interactions occurring between the components themselves (direct interactions) and between the interactions within the overall system (indirect interactions; Rao *et al*. 1998; Etienne and Bergeez 2004).

Competition

The major resources that influence silvopastoral productivity are nutrient, water and light availability and their utilization by the different components of the system. Generally, it is thought that trees reduce grass productivity through competition for the above (light) and below ground (water and nutrients) resources (Fernandez *et al*. 2002). However, competition will not be expressed as long as resource availability exceeds the demand of the crops (trees and grasses) needs. As soon as this condition is not met, competition will begin.

Competition for light

Light intensity and quality is fundamental for the growth and development of many tropical forage grasses. Most grasses growing naturally in tropical regions are C_4 species which do not reach light saturation even with maximum solar radiation (Jones 1985). In addition, in a tree – grass mixture, trees influence and reduce the quantity and quality of light reaching the soil surface. Tree canopies intercept and absorb photosynthetically active radiation (PAR) between 400 – 700 nm wave bands, depressing photosynthetic activity of grasses compromising its growth (Rao *et al.* 1998; Montard *et al.* 1999; Sharrow 1999). C_3 grass species become light saturated at lower light levels than C_4 grass species. As result, photosynthetic rates are decreased to a higher extent in C_4 grasses (Jones 1985; Kephart 1992). However, to compensate the lower levels of incident radiation, shaded C_4 grass species increase their light use efficiency (Wilson and Ludlow 1991; Cruz 1997; Andrade 1999). Improved radiation use efficiency by C_4 grasses have been attributed to morphological and physiological adaptations that pastures adopt under shade environments (Kephart *et al.* 1992; Cruz 1997; Dias-Filho 2000; Lin *et al.* 2001). Morphological adaptations of pastures in light reduced environments to capture more light include internodal, leaf and stem elongations. Shading also promotes an increase in plant height and specific leaf area and a decrease of tillering, specific leaf dry weight and leaf thickness (Kephart *et al.* 1992; Denium *et al.* 1996; Lin *et al.* 2001; Fernandez *et al.* 2004).

Physiological adaptations to favor photosynthesis include delaying initial flowering, reducing light interception by less efficient stem tissue, allocating more resources to produce more leaf tissue than to roots, lowering respiration rates, reducing stomatal apertures and improving CO_2 assimilation rates (Cruz 1997; Carvalho *et al.* 2000; Dias-Filho 2000).

Belowground competition

Competition for belowground resources between trees and grasses in silvopastoral systems is mainly for water and nutrients, although competition with other organism (i.e. pests, insects) and other competitive forms (i.e. allelopathy) within the system may occur (Rao *et al*. 1998).

Generally, nitrogen is the most limiting factor affecting pasture productivity, but soil moisture can be the major limiting factor affecting plant growth in arid and semiarid areas. As a result, it is generally thought that belowground competition between trees and grasses in semi arid tropical areas is mainly for water rather than for nutrients (Ong *et al*. 1991). Moreover, it is assumed that this competition occurs in the upper soil layers due to the fact that grasses have more numerous roots that are confined to the upper soil horizons while trees have roots that are distributed in both upper and lower soil horizons (Walter 1971; Harmannd *et al*. 2003).

Various studies have documented the belowground competitive effects between trees and herbaceous understorey vegetation. In a study in the Patagonia steppe (Salas *et al*. 1989) experimental removal of grass increased tree growth significantly indicating that grass reduced the resources available for tree growth. Similarly, in Kenyan savannas, Belsky (1994) found that trees were competing with grasses for belowground resources at high-rainfall site (> 750 mm rain $year^{-1}$) site, but not at low rainfall sites (< 450 mm rain $year^{-1}$). The results found are explained by the root pattern that the trees adopt growing under different soil moisture gradients. At drier sites, trees extend their roots farther into the grassland areas as an adaptation mechanism to explore larger volumes of soil to acquire water. At the wetter sites, water is less scarce therefore tree roots end near or under tree canopies and hence trees advantages pastures (Belsky 1994; Lehman *et al*. 1998; Harmannd *et al*. 2003).

It has also been demonstrated that trees improve soil quality by allocating higher nitrogen and other nutrients associated with organic matter under their canopies which implies higher nutrient availability to plants compared to open grassland areas (Belsky *et al*.

1989a; Belsky 1994; Durr and Rangel 2000; Ludwing *et al*. 2001; Power *et al*. 2003). However, the higher nutrient concentrations under tree canopies are not always accompanied by higher grass productivity. This suggests that trees are competing with grasses for nutrients, or that other factors (such as hervibory) apart from nutrients are limiting the production of grasses under tree canopies (Ludwing *et al*. 2001).

Despite the existing evidence on the competition effects between trees and grasses, the exact mechanisms on how these effects occur are yet unclear. What is certain is that the degree of competition will depend on site conditions, characteristics and requirements by grass and tree species present in the silvopastoral systems as well as on nutrients and water availability in the soil.

Facilitation

Facilitation occurs when one system component supports the productivity of another component (Holmgren *et al*. 1997; Eitienn and Bergez 2004). Generally, microclimate modifications and increased nutrient availability are the most common forms that plants and animals benefit each other within silvopastoral systems (Sharrow 1999).

Impact of trees in pasture productivity and quality

The impact of trees in the production and quality of pasture growing in silvopastoral systems has been controversial. Both higher and lower pasture production has been found to occur under tree canopies in a wide range of ecosystems. These varied results have been associated with different factors such as soil fertility (Durr and Rangel 2001), climatic conditions (Belsky 1989; Ludwing *et al*. 2001), grass species (Kephart *et al.* 1992; Dias-Filho 2000) as well as densities, configuration and characteristics of tree species present in pastures (Belsky *et al*. 1989; Teklehaimanot *et al*. 2002; Fernandez *et al*. 2002; Harmannd *et al*. 2003). Increased pasture production has been associated with the improved soil fertility and microclimate conditions produced by trees (Belsky *et al*.

1989; Fernandez *et al*. 2002). On the contrary, lower pasture production under tree canopies has been related mainly to competition between trees and pasture for the above (light) and below (water and nutrients) resources whitih tree canopies.

Most tropical grasses do not grow well under high shade levels (< 30 % that of full sunlight), with some exceptions. *Panicum maximum* has been reported to be a highly shade tolerant grass species (Wong 1990; Bhatt *et al.* 2002). Other grass species like *Brachiaria brizantha, Brachiaria mutica*, *Brachiaria decumbens*, and *Cenchrus ciliaris* adapt well to medium (35 to 65 %) shade levels (Wong 1990; Bhatt *et al.* 2002; Carvalho *et al.* 2002). Shade adaptation of these species has been attributed to the ability of these grasses to develop morphological and physiological adaptation in response to low light intensities and thus adjust their photosynthetic behavior (Dias-Filho 2000). In Brazil, Carvalho (1997) found that *Brachiaria brizantha, Panicum maximum* and *Brachiaria decumbens* under 30-40 % of shade grow at relative rates of 97, 77 and 63 % respectively compared to when they grow in full sun. Species like *Andropogus gayanus* and *M. minutiflora* produced 41 and 36 % respectively under shade (60-70% PAR transimitted) in comparison to full sunlight. These results show the importance of selecting the proper grass species upon the success of the silvopastoral system productivity.

On the contrary, higher pasture production has been reported, under some individual tree species, particularly leguminous trees (Belsky *et al.* 1989; East and Felker 1993; Durr and Rangel 2000; Fernandez *et al.* 2002; Power *et al.* 2003). The higher yields have been associated with increased soil N levels under the N_2 fixing tree species and to the higher mineralization rates under tree canopies favored by a more favorable microenvironment. Similarly, tree species characteristics (i.e. crown size, crown type, root pattern) influences pasture productivity. Very dense tree crowns (i.e. *Mangifera indica*, *Ficus spp* and *Adansonia digitata*) can reduce dry matter production to a larger extend when compared to pastures growing under lighter crown canopies such laurel (*Cordia alliodora*) cedro (*Cedrela odorata*) and *Acacia tortilis* because the former reduce light to a larger extent (Beslky *et al.* 1989; Villafuerte 1998; Souza de Abreu *et al.* 1999) altought belowground competition may has also being importat.

The cover, density and arrangements of trees in silvopastoral systems play important roles in pasture productivity. Many studies have shown that by increasing tree cover and or tree density, pasture production is reduced to a larger extent (Acciaresi 1994; Giraldo *et al.* 1995; Jackson and Ash 1998; Knowledes *et al.* 1999; McElwee and Knoweles 1999; Ares *et al.* 2003; Etienne 2004; Douglas *et al.* 2006). This can also be true for systematic silvopastoral systems (i.e. forest/fruit plantations) whereas the tree canopy closes, herbage biomass declines linearly. However, for traditional silvopastoral systems where a large diversity of tree species occur dispersed in pastures this may not be the case. Recent studies conducted by McElwee and Knowles (1999), Platis and Papanastasis (2003) and Alvim *et al.* (2004) in traditional silvopastoral systems have shown that available DM of *Brachiaria decumbens*, a high shade tolerant grass specie, increased under medium tree cover (22 %) and then decreased at high tree cover (30 %).

Trees also affect pasture quality. Light reduction from shade was shown to modify the chemical composition of pastures, increasing crude protein and diminishing the non-structural carbohydrates (Kephart 1993). Pasture nitrogen (N) concentrations tend to be higher under trees, since pastures under tree canopies generally have access to higher nutrient levels than in open areas (i.e. full sun) especially in those areas with low soil fertility or in places with N deficiency where trees can lead to a higher biomass production. A more efficient nutrient cycle in the plant – soil system could be one of the main factors explaining the higher N and crude protein concentrations in the forage produced under shade. This could be possible due to an apparently enhanced mineralization rate of soil N under the shade as a result of a more favorable microclimate conditions (Wilson *et al.*1990; Cruz 1997). Higher CO_2 assimilation rates of leaves under shaded areas are probably due to the higher quantities of N and this may also contribute to higher pasture quality under tree canopies (Wong and Wilson 1980). Belsky (1992) found that N, P, K, Ca, B and Cu concentrations in forage tended to increase in areas close to tree canopies.

Most of the research comparing crude protein content of forages growing under tree canopies to those at full sunlight in a wide range of ecosystems showed that CP content is higher under tree canopies (Andrade 1999; Frankie *et al.* 2001; Penton 2001). Muir *et al.* (2001) reported that CP percentage was 15 % higher for legumes and 9 % for pastures growing at half the distance from stem to the canopy edge than for grass growing at twice the distance from the canopy edge. Similar results, but with lower percentages, were obtained by Andrade (1999) in pastures growing at half the distance from stem to the canopy edge compared to grass growing at full sunlight or at high shaded areas. Pasture dry matter digestibility, cellulose, neutral and acid detergent fiber growing beneath tree canopies are generally lower compared to those growing outside tree canopies (Belsky 1992) but these responses have been generally less consistent than that of crude protein.

Microclimatic modifications

Trees are able to provide a number of microclimatic benefits to grasses that are growing under their canopies through several mechanisms. Trees oftentimes lower soil and ambient temperatures under their crowns, especially in dry and hot regions and particularly during prolonged drought periods (Belsky *et al*. 1989b; Brenner 1996; Rao *et al*. 1998). In the semi arid regions of Kenya trees reduced soil temperature by 6 °C at 5 and 10 cm depths when compared with open areas (Belsky *et al.* 1989b; Belsky *et al.* 1993a). Similarly, underneath *Faidherbia* trees, soil temperature at 2 cm deep was reduced by 5 to 10 °C (Vandelbeldt and Williams 1992). Reduced soil and ambient temperatures under tree canopies reduce soil water evaporation, provide higher humidity, reduce water stress by crops, maintain higher rates of water availability and increase microbial activity in comparison with open areas. In consequence, improved microclimatic conditions under tree canopies favor a faster release of nitrates promoting higher nutrient uptake by grass and favoring pasture production (Wilson and Ludlow 1991; Belsky 1992; East and Felker 1993).

Trees also shelter pastures by reducing wind speed. Singh *et al.* (1998) found that wind speed was reduced by 20 to 25 % in *Leucaena* hedgerows favoring crop growth. In the same sense, Montard *et al.* (1999) reported that the wind speed reaching the pasture in a silvopastoral system was only 68 % of the control (pasture without trees). Wind reduction diminishes the detrimental desiccating effect that winds have on pastures, helping them to conserve water.

Soil improvements

The presence of trees in pastures contributes to increasing pasture productivity by improving soil physical and chemical properties, reducing erosion rates and increasing nutrient cycling (Belsky *et al*. 1989a; Belsky *et al*. 1993b; Wilson and Ludlow 1991; Lin *et al*. 2001; Gibbons and Boak 2002; Power *et al*. 2003). Generally there is a fertility gradient which diminishes from the tree base to beyond the shade of the canopy (Belsky, 1994). Soils beneath trees have higher organic matter levels and greater litter cover than soils in the open. They also have more extractable phosphorus (P), potassium (K) and calcium (Ca), which improves soil fertility (Belsky 1989b; Rao *et al.* 1998). Leguminous trees enhance soil fertility by adding nitrogen through nitrogen fixation and by accumulating organic matter (litter fall) beneath them, particularly in the topsoil layer (0.20 m).

Cattle grazing the paddocks recycle and redistribute soil organic matter and nutrients (N, P, K and sulfur) through cattle dung and urine. It has been found that areas with cattle dung have higher nutrient concentrations (K, P and Ca) especially during the first week of deposition (Barrios *et al.* 1999). Similarly sulfur (S), N and K concentrations are higher in areas close to places where cattle urinate. However nearly 75 % of nitrogen content in the urine is in the form of urea and is readily volatilized, resulting in high loss of N. Similarly, high percentages of S and K ingested by cattle are recycled through the urine as an inorganic S and inorganic K but large amounts are loss by lixiviation before the plants can utilize it.

Contribution of dispersed trees in pastures to farm productivity

The integration of multipurpose trees dispersed in pastures from natural or artificial regeneration may contribute to increased farm productivity through the products and services they provide to cattle farms. Among the products that trees provide are forage and fruits, timber, poles and firewood. In the same sense, trees provide shade and shelter for cattle, as well as environmental services such as biodiversity conservation, watershed protection and carbon sequestration. (Barrios *et al.* 1999; Pezo *et al.* 1999; Harvey and Haber 1999; Camargo *et al.* 2000; Frankie *et al.* 2001, Camero *et al.* 2000; Casasola *et al.* 2001; Ku 2005). In the future farmers may receive additional income from payments for the provision of environmental services (Pagiola *et al.* 2004).

Forage and pods of multipurpose trees to cattle

Dispersed trees in pastures produce both leaves and pods that are used as feed source by cattle. Leaves and pods of multipurpose tree species (MPT) generally contain higher crude protein (>12%) and *in vitro* dry matter digestibility (54 – 80%) than grasses (Blair 1990; Lowry 1994; Benavides 1999; Durr and Rangel 2002; Ku 2005). Apart from their high nutritional levels, some MPT loose their leaves and/or produce pods during the dry period when pastures are constrained by insufficient quantities of high quality dry matter. Most grasses contain poor dry matter digestibility (< 38%) and low crude protein (< 7%) during this time of year to meet cattle nutritional requirements (Minson 1990; Lowry 1995).

Fortunately, farmers are aware of these problems and know about the potential benefits that MPT have for maintaining animal productivity during the dry season (Muñoz *et al*. 2003). Tree fruits have been widely used as feed for cattle in dry tropical areas particularly during the dry season (Blair 1990; Lowry 1994; Kass 1994; Benavides 1999; Durr and Rangel 2002; Ku 2005). It has been reported that species like *Samanea saman* (genizaro) and *Enterolobium cyclocarpum* (Guanacaste) can produce up to 270 kg fresh fruit tree^{-1} year^{-1} (Durr 2001; Roncallo *et al.* 1996). Gaucimo *(Guazuma ulmifolia*) trees can produce about 50 to 60 kg of edible dry matter forage for cattle (Giraldo 1996) and in Nicaragua carbon trees (*Acacia pennatula*) were shown to produce between 28 to 35 kg of fruits tree^{-1} (Casasola 2000) which can serve to supplement cattle. In this manner trees can contribute to increase cattle productivity, mainly in dry areas and during prolonged dry seasons, where farmers are forced to look for supplementary feeding alternatives and trees may be the only feasible source available.

An additional advantage to fruit production is that pastures of cattle farms generally present a wide diversity of multipurpose tree species which produce fruit with different nutritional quality during the dry seasons that are available to cattle. Thus, different combination of tree species with different fruit quality production patterns could favor cattle productivity in such a way that diverse fruit variety provides a more stable feed source during the dry season than pasture monocultures from which cattle can better balance their nutrient requirements according to fruit availability and quality. Moreover, cattle can collect the pods directly from the ground, thus avoiding fruit waste and the extra labor cost to supplement cattle.

Timber

Although a long term activity, timber extraction is another valuable product obtained from farm trees. There has been a tendency to increase timber extraction from pastures in relation to the total timber harvested volume authorized as forest areas become less available (Morales and Kleinn 2001). In Costa Rica, the volume approved for timber extraction from forest areas decreased from 1990 to 1995 whereas that volume coming from pastures increased. Nearly 20 % of the total volume of timber (m^3) extracted during that period came from trees outside the forest, including dispersed trees in pastures (Morales 2000).

Planting timber tree species in pastures can represent a great opportunity to diversify farm income and at the same time increase cattle farm productivity. Economic results have shown that timber trees associated with pastures (silvopastoral systems) can be more profitable than just cattle and pasture (traditional systems). In a pine plantation, Sharrow *et al.* (1996) reported a 30% higher farm income in a silvopastoral system than pastures or forest plantation as monocultures. Similarly, Hoffman *et al.* (1992) reported higher profitability in a system with trees in pasturelands ($2188.00 US) compared to monoculture pasture production ($ 1478.00 US). Despite the apparent economic benefit, planting trees involves a high initial investment by farmers to buy tree seedlings and protect them from cattle damage, and this could limit adoption of SSP (Alonzo 2000). This situation can be reversed if policies, taxes and incentives are promoted among cattle farmers that favor tree planting and allow trees to regenerate naturally in pastures. Thus, the high initial seedling and labor cost would be reduced considerably (Camargo 1999; FAO 2005).

Shade and shelter to cattle

Many farmers leave trees dispersed in pasture with the purpose of improving microclimatic and soil conditions and providing shade and shelter to cattle (Harvey and Haber 1999; Casasola, 2000; Muñoz *et al*. 2003). Tree shade improves cattle welfare, decreasing cattle transpiration rates, reducing heat stress and favoring dry matter voluntary intake, and can consequently improve cattle productivity (Fuquay 1981; Blackshaw y Blackshaw 1994; Sharrow 2000; Restrepo 2002; Souza de Abreu 2002; Betancourt *et al*. 2003). It has been demonstrated that livestock prefer to graze under tree canopies that are not too dense, nor too scarce due to the favored environmental conditions that trees provide under their canopies compared to monoculture pasture stands (Platis and Papanastasis 2003). Grazing pastures with tree cover have shown to increase cattle body weight gains and milk production. Souza de Abreu *et al*. (1999) in the humid tropics of Costa Rica and Betancourt *et al*. (2003) in the dry tropics of Nicaragua found an 9% and 29% increase in milk production respectively when dairy cows grazed in shaded paddocks with scattered dispersed trees in comparison to cows that grazed in unshaded or in pastures with low tree cover. Similarly, cattle grazing in paddocks with medium tree cover gained more live weight than cattle grazing high or low tree cover paddocks (Restrepo *et al*. 2004). The higher milk production and live weight gains observed were attributed to the improved cattle welfare provided by shaded paddocks. Cattle grazing in moderate shade paddocks spent more time grazing and less time resting, which increased their voluntary dry matter intake in comparison to cattle grazing in unshaded paddocks (Sharrow 2000; Restrepo 2002; Betancourt *et al.* 2003; Souza de Abreu *et al.* 2003).

Biodiversity conservation

Approximately 40% of Central America is covered by pastures (Ibrahim *et al.* 2001), which provide habitats for a few terrestrial species when compared with tropical forest areas (Lugo 1986). In pasture ecosystems, trees are usually present in low densities and woody seedlings are generally eliminated by cattle damage during grazing or manually or chemically by farmers (Camargo *et al.* 2000). In consequence, plant diversity and related animal species is low. On the contrary, dispersed trees in pastures can serve to form biological corridors or stepping stones in fragmented agricultural landscapes to favor the movement of fauna between pastures and natural habitats (Snelder 2001; Harvey *et al.* 2005). Maintaining dispersed trees in pastures can provide perching, nesting and roosting sites for migratory and resident birds. They also serve as foci for seed dispersal and plant recruitment (Guevara *et al.* 1998; Harvey, 2000) which are higher under their canopies (Nepstad *et al.* 1990; Otero– Arnaiz *et al.* 1999). Some Costa Rican farmers are using fruiting trees in their pastures to attract charismatic bird species aiming to develop the eco-tourist potential of their farms (Cardenas *et al.* 2000).

Description of tree species in the study

***Acrocomia aculeata* (Jacq.) Lodd. ex Mart.** *(Coyol, Aracaceae)*

This species is a fire resistant palm that is widely found in tropical areas from Mexico to Argentina. It posses large spiny stems that grow up to about 15-20 m in height and up to 10-50 cm in diameter (Zamora *et al.* 1999). This canopy is typically composed of 20-30 pinnate, plumose leaves up to 10 feet long (3 m) and has leaflets about 3 ft (0.9 m) long which possess long needle-like black spines. The unisexual yellow flowers (both sexes at the same stalk) are borne on a 6 ft (1.8 m) long inflorescence. The flower stalk emerges up to 7 feet long (2.1 m) which are followed by light green fruits that are about 2 inches (5.1 cm) in diameter. The fruit is smooth, the epicarp is fragile and crack easily at maturity whereas the mesocarp is fibrous and yellow. Fruits are largely appreciated by cattle since they avidly search for the fruit dispersed on the ground during grazing. (Uhl and Dransfield 1987; Scariot and Lleras 1995; Zamora *et al.* 1999; Gutierrez-Velazquez and Peralta 2001).

***Cordia alliodora*. Ruiz & Pav.** *(Laurel, Boraginaceae)*

Cordia alliodora is a highly appreciated and valued timber tree species commonly found in farms in Costa Rica. It grows up to 30 m in height with a straight single trunk and develops an elliptical crown with a distinctive branching pattern which maks this species suitable for agroforestry systems (Valdivieso *et al.* 1998). Leaves are simple and alternate in clusters. Leaf abscission occurs during the mid-late dry season and variation in the onset is present between individuals at the same location and of same age with deciduousness being delayed and less pronounced in younger trees. (Holdridge and Poveda 1975; Geilfus 1989; Bellow and Nair 2003)

***Enterolobium cyclocarpum* (Jacq.) Griseb.** *(Guanacaste, Leguminoseae)*

This is an enormous canopy indigenous *mimosaceous* leguminous tree originall found from Mexico to Brazil in dry climates from about 700 – 1100 meters above sea level. Trees have dark red brown heartwood, which is quite fungus resistant, but on the contrary, the sapwood is quickly destroyed by insects. Trees drop their leaves during the dry season and new leaf production begins 4 – 8 weeks before the beginning of the rainy season. Full-sized green fruits begin to mature and turn brown during this period. Immature fruits size are around 2 cm in length until January, at which time they expand rapidly to a green fruit of 10 – 14 cm diameter. The mature dark brown indehiscent dry fruits have high protein content (> 12 %) and are highly digestible (> 70 %). They fall from March to April, and in pasturelands there are avidly eaten by cattle. The hard, dormant seeds do not germinate unless the seed coat has been scarified by wear, gut passage, or by mechanical filing. However, if the seed coat has been penetrated, there is 100 % germination in a moist habitat. Seedlings are killed by desiccation, trampling, fire and by competition with grasses. Apart from cattle feed, tree uses include posts, fuelwood and lumber. (Holdridge and Poveda 1975; Janzen 1982b; Geilfus 1989; Mora 1990; Ku 2005)

***Guazuma ulmifolia* Lam.** *(Guacimo, Sterculiaceae)*

Guazuma ulmifolia trees are generally present below 500 m above sea level and commonly found in open areas in regions with mean annual temperature above 24°C and a well defined dry season from Mexico down to Argentina. This tree grows up to 4 to 10 m in height with 60 cm dbh. The trees characteristically have a rounded crown type and drooping foliage except in very dry areas where leaves are dropped at the end of the dry season. In areas with distinct bimodal climate, flowering occurs during the dry season. Leaves are simple, alternate with serrate margins, 5-7 cm long. Flowers are yellow-brown, about 1 cm long in 3-5 cm long. The fruits are round or elliptic 5-celled capsule that open at the apex. When the fruit is ripe, it is black and contains 40-80 gray seeds, each 3-5 mm in diameter. It is considered a multipurpose tree, its main use has been reported as an important source of fodder for livestock. It serves as a shade tree for cattle and the wood is used for firewood, charcoal, posts and construction. Fruits contain around 8 to 9 % of crude protein and around 79 % of fiber with a nice smell which makes them appetizing to cattle. (Janzen 1982a; Geilfus 1989; Ortega *et al.* 1998; Giraldo 1999; Jiminez-Ferrer 2000; Ku 2005)

***Samanea saman* (Jacq.) Merr.** *(Genizaro, raintree, leguminoseae)*

Genizaro is a very large native tree found within the moderate to heavy rainfall zones from México to northern South America. It is commonly found dispersed in pastures of cattle farms as a shade tree or found widely distributed in the tropics as a garden tree. It belongs to the M*imosaceae* subfamily. In the deciduous forest, it drops its leaves but it is evergreen in the rain forest. It is a rapidly growing tree with a trunk diameter greater than 1.8 m 4.5 m tall. The heartwood is a durable, dark color and highly appreciated for furniture wood. Raintrees have large, long and spreading branches covered with rough bark. The florets in the inflorescences produce miniature fruits (3 – 5 cm long) that remain small for at least 8 months after which they rapidly enlarge and their seeds mature. Twisted mature fruits are 10 to 20 cm long and fall from the leafless branches during mid dry season (March). However, adjacent trees or different branches within the same tree may be out of phase by at least one month. In natural habitats, the fallen fruits eventually root when the rainy season begins, but in pasturelands, cattle are avid fruit eaters since fruits are a good source of proteins, carbohydrates and minerals. Nutritive value of fruits ranges from 13 – 15 % for crude protein and around 65 % for digestibility. Unfortunately, seeds have been found to contain toxic alkaloids, which are also present in leaves, seeds and wood of the plant. (Holdridge and Poveda 1975; Janzen 1982; Geilfus 1989; Durr 2001; Ku 2005)

***Tabebuia rosea.* Bertol** *(Roble de sabana, Bignoniaceae)*

Roble de sabana, as it is commonly known, is a deciduous highly valued native timber tree of Tropical America from the south of México passing through Central America down to Venezuela, Colombia and Ecuador. This tree grows up to 30 m (average 20 m) in height with 1 m girth in places between 1500 and 2000 mm of rainfall, temperatures above 26ºC and at 1000 m.a.s.l with deep and superficial soils, but grows better in well-drained soils with light textures. Crown architecture is wide, stratified and irregular with horizontal branches and straight boles which can be a limiting factor for use in agroforestry systems (Lujan and Somarriba 1993). Leaves are decussate, compound, digitate, long, and petiolate and are dropped from March through June. Flowers are hermaphrodite in solitary or grouped inflorescences; flowering occurs the first month of the year. Seeds are white, thin and easily dispersed by wind. Seed germination occurs at shade as well as at full sunlight (Holdridge and Poveda 1975; Geilfus 1989; Instituto Nicaragüense de Recursos Naturales y del ambiente IRENA, 1992).

CHAPTER III

Relationship between dispersed trees in pasturelands and cattle farms in a tropical dry ecosystem in Cañas, Guanacaste, Costa Rica.

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Abstract

Maintaining or increasing trees in farmlands may provide a means of augmenting the productivity, profitability and sustainability of livestock farms. However, little is known about the diversity, abundance, richness and species composition of trees dispersed in pastures of cattle farms and whether such characteristics vary across different cattle farm types. Therefore, a characterization of the dispersed trees in pastures was conducted in 16 cattle farms (classified by farming system and size) in a tropical dry ecosystem in Costa Rica. A total of 5,896 dispersed trees from 99 species and 36 families were counted. Trees were present on 100 % of the farms and in 85 % of the paddocks. The most abundant families were *Bignonaceae*, *Sterculeaceae*, *Boraginaceae*, *Arecaceae* and *Papilionaceae.* The most common tree species were *Tabebuia rosea*, *Guazuma ulmifolia*, *Cordia alliodora* and *Acrocomia aculeata*, which together accounted for 60 % of the total number of trees. Dispersed trees in pastures occurred as individual trees (54 %) and in clusters (46 %) but no differences in dispersion were observed across farm types. Crown cover (m^2 ha^{-1}) and tree density (individuous ha^{-1}) were significantly higher on small beef cattle farms than on mixed (beef + agriculture) farms. No significant differences were found for Shannon and Simpson diversity indices among the farm types studied. It is concluded that farmers are managing a wide diversity of trees dispersed in pastures but at low densities with the objective of fulfilling different farm needs and minimizing interference with pasture productivity.

Key words: Abundance, diversity, farm types, richness, silvopastoral systems, tree cover.

Introduction

In Central America, pastures have generally been established immediately after cutting and burning primary forest, or after two to five years of shifting cultivation with crops such as maize (*Zea mayz*) and beans (*Phaseolus vulgaris*) followed by planting with forage grasses (Ibrahim *et al*. 2000). While large areas of forest have been converted to pasture, the benefits of the conversion are temporary, due to the rapid depletion of soil nutrient reserves resulting in pasture degradation. This in consequence causes a decrease in animal productivity and negatively affecting the profitability of beef cattle enterprises (FAO 2000; Rueda *et al*. 2003).

Silvopastoral systems may provide a means of increasing the productivity, profitability and sustainability of livestock farms (Szotts *et al*. 2000; Devendra *et al*. 2004; Kallenbach *et al*. 2006). Many farmers are constrained by the lack of resources (land and / or capital) to establish and manage forest plantations and rarely have fruit plantations (Scherr and Current 1997), but they often retain dispersed trees and live fences within their pasturelands instead to minimize risk, diversify production, and obtain services as well as economic benefits (Beer *et al*. 2000; Gibbons and Boak 2002; Devendra and Ibrahim 2004). Among the benefits that trees provide to cattle farmers are timber, fence posts, firewood and food. Trees can also be an important source of shade, shelter and forage to cattle. From an environmental viewpoint, silvopastoral systems can serve as stepping stones for animals and birds (Snelder 2001), enhance landscape connectivity and aesthetics, provide environmental services (i.e. carbon sequestration), protect watershed and conserve biodiversity (Guevara *et al*. 1998; Harvey and Haber 1999; Pagiola *et al*. 2004; Harvey *et al.* 2005). As such, many benefits may be obtained from tree cover in cattle farm systems.

Most of the research on traditional silvopastoral systems in the tropics has focused on the evaluation of the production and nutritive value of native trees and shrubs for feeding cattle, especially during the dry season (Topps 1992; Solorio *et al*. 2000). While these studies provide a solid basis for the use of trees and shrubs in cattle farm enterprises, there is limited information about the patterns of richness, abundance, distribution density and cover of tree species in pastures of cattle farms. Even less information is available on how this tree cover varies across farm types or what factors contribute to patterns of tree species distribution. Understanding the patterns, structure and composition of tree resources in pastures, and how these vary across the landscape and across different production systems is critical for designing incentive schemes and policies for increasing and conserving tree resources in agricultural landscape dominated by cattle. The objective of this study was to characterize and describe the diversity, abundance, richness and arrangement of trees dispersed within pasturelands of different cattle farming systems in Cañas, Costa Rica and to explore the relationships between tree cover and farm type with the aim of providing information that promotes tree planting on farms and helps in the design of more productive silvopastoral systems.

Methodology

Site description

The study was conducted in Cañas, Guanacaste, Costa Rica located at 10^{o} 11´ N and 84^{o}15´ W. Cañas is situated in the Pacific zone of Costa Rica and covers an area of 684.20 km^2. The area is classified as Tropical Dry Forest (Holdridge 1978) with elevations ranging from 60 to 250 masl (Arauz 2001). Annual rainfall ranges from 1000 to 2500 mm, with most rain falling during May through November (wet season) and the dry season occurring from December through April. During 8 months of the year evapotranspiration is higher than precipitation. Mean annual temperature is 27.6 ºC. Average mean temperature varies between 23 ºC and 31 ºC during the year. Relative humidity fluctuates between 62 – 89 and 52 – 77 % in the wet and dry seasons, respectively (Taboga Meteorological Station 2003). Soils in the lowlands are of volcanic type origin and mainly vertisols with an average depth of 100 cm. In the upland and slope areas, soils are mainly inceptisols with rock formations on the soil surface. Soils are well drained, texture varies from fine to medium and fertility goes from medium to very high (Arauz 2001).

Farm selection

For the inventory of tree resources in pastures, biophysical and socioeconomic information available from a semi-structured survey of 53 livestock farms from the FRAGMENT project were used to define the livestock farming systems present in the region. Farms were first grouped by production system as either beef (just cattle) or mixed (agriculture and cattle) cattle farms. Beef cattle farms were then subdivided by size into small (1- 50 ha), medium (51 – 100 ha) and large farms (> 100 ha). Mixed farms were not subdivided because most farms of this type were small (< 50 ha). All farms were placed in a frequency distribution table according to the farm type to which they belonged and twelve beef cattle farms (four small, five medium and three large) and four small mixed farms were selected based on farmer willingness to cooperate in the study.

Each farm selected was identified in a panchromatic image of the area taken in 2001 by the Ikonos© satellite and available to the FRAGMENT project. The spectral range of the image lies within 0.45 to 0.90 microns and the spatial resolution on ground is 1 m. The image used was radiometrically and geometrically corrected. Farm boundaries of the selected farms were delimited according to the land registration office maps and verified by walking the farm limits and by consulting with the owner/manager. Additionally, within each farm, all plots, of particular land uses, were identified and classified by photointerpretation as forest, crop land, pastures, riparian forest, charrales (areas under vegetal succession) and human settlements. Classifications were later verified directly in the field. Farm boundaries and plot limits were delineated directly in the satellite image using GIS (ArcView 3.3; ESRI). For pasture plots, hereafter referred to as paddocks, information about the grass species was recorded by direct observations in the field. The age (year of plantation) of pasture sown was recorded during an interview with the owner/manager. Total farm area and the area of each individual plot per farm were estimated using ArcView 3.3.

Tree inventory

A detailed inventory of all trees larger than 10 cm in diameter at breast height (dbh) dispersed within the paddocks (n =196) of the 16 selected farms (total area of pastures = 835.76 ha) was carried out from June to December 2002. The inventory of dispersed trees was carried out on tree population within each paddock. Dispersed tree were identified to species level directly in the field with the participation of local farmers. For those individuals that could not be identified in the field, leaf and fruit specimens were collected and identified later by taxonomists from the Santa Rosa National Park, Guanacaste, Costa Rica. Riparian trees, live fences and forest patches (groups of trees covering > 0.25 ha) were excluded from the pasture tree inventory, because they were not considered to be trees dispersed in pastures.

In order to characterize the types of trees dispersed in pastures, these were classified according to their main uses as either timber, forage (trees producing foliage and/or pods that are eaten by cattle) or fruit bearing trees. Other tree uses (e.g. firewood, fence posts, etc) were not considered. Decisions to assign species to categories were based on personal communication with farmers (Cañas, June 2002), secondary information (Stokes 2001) and specialized literature (Jimenez *et al*. 1999). In some cases tree species, such as *Enterolobium cyclocarpum* (Jacq.) Griseb and *Samanea saman* (Jacq.) Merr, were classified in more than one category due to their various reported main uses. At the same time, trees were also categorized according to how they were distributed in pastures, as individuals or as clusters of trees (defined as trees forming groups where their crowns overlapped).

For each tree, the diameter at breast height (dbh), total height, stem height and crown cover were measured directly in the field. Diameter at breast height was measured with a diametric tape and expressed in centimeters. Tree heights were measured with a hand-held laser instrument (Impulse 200 LR), which calculates the heights in meters based on sensor readings of distances and vertical angle measurements. Crown cover of individual trees was measured from the readings of two perpendicular measurements covering the longest axes of the crown (Bellow and Nair 2003), whereas for trees in clusters the overlapped canopy was considered as a single canopy and the two longest perpendicular axes were measured. Tree crown cover area was calculated utilizing the following formula:

$$A = (\pi * R1 * R2)$$

Where:

A = Area (m^2)

π = 3.1416

R1 = Radius of crown axe 1 (m)

R2 = Radius of crown axe 2 (m)

Total paddock crown cover percent was calculated as the sum of all tree crowns measured in the field for a particular paddock divided by the total paddock area and multiplied by 100.

Data analysis

A complete randomized experimental design with four farm types (treatments), small, medium, large beef cattle and mixed (beef and agriculture) farms and four replicates (farms) was used. Descriptive statistics (mean, standard error, ranges, minimum and maximum), standard descriptors of vegetation composition (density, abundance, richness) diversity (Simpson and Shannon) and similarity (Jaccard) indices, were calculated for each paddock and the mean of all paddocks was considered for the farm level.

Jaccard index was calculated from the equation $Cj = \frac{j}{a + b - j}$ where j = the number of species found in both sites, a = the number of species in site A and b = the number of species in site B. Simpson index was calculated from the equation $D = \Sigma p_i^2$ and Shannon index was calculated from the equation $H' = - \Sigma p_i \ln p_i$ where p_i is the proportion of individuals found in the $_i$th specie and ln = is natural logarithm.

One way analysis of variance was performed to test differences between farm types as well as between tree size measurements for the most abundant species. Duncan multiple comparison tests were used to test mean differences. Diversity indices were calculated for each paddock using Biodiversity Pro (McAleece *et al.* 1997) and Estimates (Colwell 1997) software programs and farm mean was considered for the analysis of variance. Multiple regression models of paddock descriptors (slope, size, distances and pasture types) as well as tree characteristics (height, dbh) were examined in relation to crown cover and tree density (dependent variables). All data was analyzed using InfoStat 4.1 (Infostat 2004).

Results

Farm characteristics

The total area of the 16 farms selected for the inventory of trees in pasture was 1,073 ha, of which pasturelands comprised 836 ha (78 %) and crown cover of dispersed trees in pasturelands was 53 ha, representing 5 % of the total inventoried area and 6.4% of total pasturelands. The remaining areas comprised primary forest (2 %), riparian forest (15%), cropped (3 %) and fallows (1.5 %) land among other land uses such as human settlements, cattle facilities and internal roads (0.5 %).

Farm size ranged from 18 to 241.3 ha, with an average of 67.0 (SE $\pm$ 14.9) ha whereas paddock size varied from 0.1 and 39.5 ha (SE $\pm$ 0.33). The percentage of area under pasture in mixed farms (47 %) was significantly ($P < 0.05$) lower than in all types of beef cattle farms which had very similar pasture percentages (mean = 81 %). Large beef cattle farms had a significantly ($P < 0.05$) higher number of paddocks (22.3 $\pm$ 4.3) per farm compared to small beef cattle (8.3 $\pm$ 1.3) and mixed farms (7.0 $\pm$ 1.8). Significant differences (P = 0.09) were found for paddock size among farm types. Duncan analysis test show that large beef cattle farms have statistically ($P < 0.05$) larger paddock sizes (6.5 ± 1.8 ha) than the mixed farm types (2.1 ± 0.6 ha).

Most of the pasture area (72 %) contained improved grass species. Among the improved species, *Brachiaria brizantha* (28 % of total pasture area) and *Brachiaria decumbens* (27 % of total pasture area) were the most frequent, while *Hyparrhenia rufa* (21 % of total pasture area) and *Paspalum spp* (6 % of total pasture area) were the most frequent naturalized and native grass species. Small beef cattle farms had significantly ($P < 0.05$) more area (mean of 93 %) covered by improved grass species than medium cattle farms (44 %) but were similar to mixed (66 %) and large beef cattle farms (89 %).

Dispersed trees in pastures

A total of 5,896 trees (dbh > 10 cm) from 36 families and 99 species were found dispersed in paddocks on the inventoried farms (Appendix 1). Of these trees, 50 % were categorized as timber trees, 27 % as forage trees and 27 % as fruit bearing trees (species can be assigned more than one use). Dispersed trees were found on all of the farms and in 170 (86 %) of the 196 paddocks inventoried. Dispersed trees in pastures were arranged almost equally between isolated individual trees (54 %) and trees in clusters (46 %). The most abundant and frequent tree species found dispersed in pastures (Table 1) were *Tabebuia rosea* (Bertol.) DC, *Guazuma ulmifolia* Lam, *Cordia alliodora* (Ruiz & Pav.) Oken, *Acrocomia aculeata* (Jacq.) Lodd. ex Mart, *Byrsonima crassifolia* (L.) Kunth in Humb. Bonpl & Kunth and *Tabebuia ochracea* (A.H. Gentry) A.H. Gentry which together accounted for 60 % of the total number of inventoried trees. Other common species found were *Pachira quinata* (Jacq.) W.S. Alverson. *Bursera simaruba* (L.) Sarg, *Samanea saman* (Jacq.) Merr, *Cedrela odorata* and *Enterolobium cyclocarpum* (Jacq.) Griseb. Of the 99 tree species recorded, 19 were represented only by one individual and seven species by two individuals.

Table 1. Summary of most abundant and frequent tree species (n = 21; dbh > 10 cm) found dispersed in pastures (n = 196) of cattle farms in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2002. Data are organized in decreasing order of abundance.

Tree species	Family	Main uses	Abundance	Relative abundance[@]	Cumulative abundance	Farms[#]	Plots[ϖ]
Tabebuia rosea	Bignonaceae	Timber	759	12.8	12.8	15	119
Guazuma ulmifolia	Sterculiaceae	Forage	742	12.6	25.4	16	117
Cordia alliodora	Boraginaceae	Timber	707	12.0	37.4	16	85
Acrocomia aculeata	Arecaceae	Forage, Fruit	632	10.7	48.1	15	78
Byrsonima crassifolia	Malpighiaceae	Fruit	434	7.4	55.5	14	61
Tabebuia ochracea	Bignoniaceae	Timber	265	4.5	60.0	14	73
Pachira quinata	Bombacaceae	Timber	183	3.1	63.1	13	33
Andira inermes	Papilionaceae	Timber	169	29	65.9	14	69
Lonchocarpus spp	Papilionaceae	Other	158	2.7	68.6	16	55
Acosmium panamense	Papilionaceae	Timber	140	2.4	71.0	9	36
Bursera simaruba	Burceraceae	Forage	127	2.2	73.2	13	29
Maclura tinctorea	Moraceae	Timber	98	1.7	74.8	12	42
Ocotea veraguensis	Lauraceae	Other	97	1.7	76.5	9	40
Hymenea courbaril	Caesalpinaceae	Timber	82	1.4	77.8	11	43
Spondias purpurea	Anacardiaceae	Fruit	81	1.4	79.2	12	30
Samanea saman	Mimosaceae	Timber, Forage	77	1.3	80.5	12	39
Myrospermun frutescens	Papilionaceae	Timber	74	1.2	81.8	10	34
Cedrela odorata	Meliaceae	Timber	67	1.1	82.9	12	43
Lonchocarpus felipei	Papilionaceae	Other	58	1.0	83.9	11	32
Gliricidia sepium	Papilionaceae	Forage	58	0.9	84.9	5	10
E. cyclocarpum	Mimosaceae	Forage, Timber	57	0.9	85.9	14	37
Other tree species	Various	Timber	834	14.1	100	na	na

dbh = diameter at breast height, [@] Out of total number of trees (n = 5896); [#] Number of farms where tree species were present (n = 16); [ϖ] Number of paddocks where tree species were present (n = 196); na = not available.

The species accumulation curve (Figure 1) shows an asymptotic nature where the initial slope is steeper and then a more gradual tail-off showing that 60 % of total tree species were found after inventorying a relatively low number of trees (600) and 80 % were found after inventorying approximately one third of the total trees suggesting that the tree density in pastures was adequately characterized.

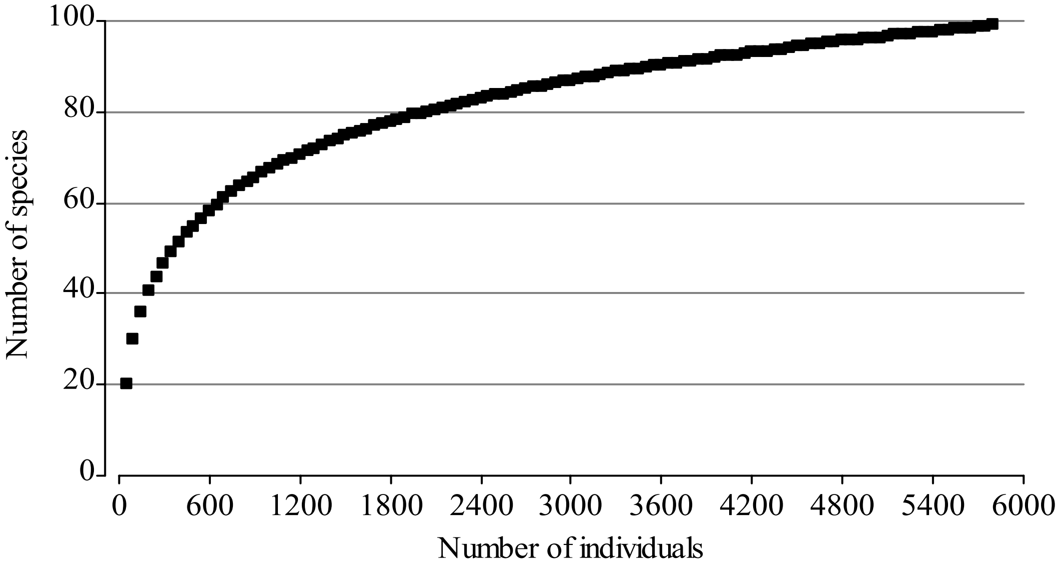

Figure 1. Species accumulation curve of trees found dispersed in pastures (n = 5,896) of cattle farms (n = 16) in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2002.

The overall mean dbh of the 5,896 trees measured was 44.8 cm (± SE 0.33) with a range from 10 to 269.7 cm. Most trees (71 %) had dbh of between 20 - 60 cm, 10 % with dbh of 10 - 20 cm and 4 % with dbh larger than 100 cm (Figure 2). The most frequent tree species with large dbhs (> 100 cm) were *G. ulmifolia* (n=54), *E. cyclocarpum* (n=29), *Ficus spp* (n=23), *S. saman* (n=18), *P. quinata* (n=11), *O. veraguensis* (n=10) and *B. crassifolia* (n=10).

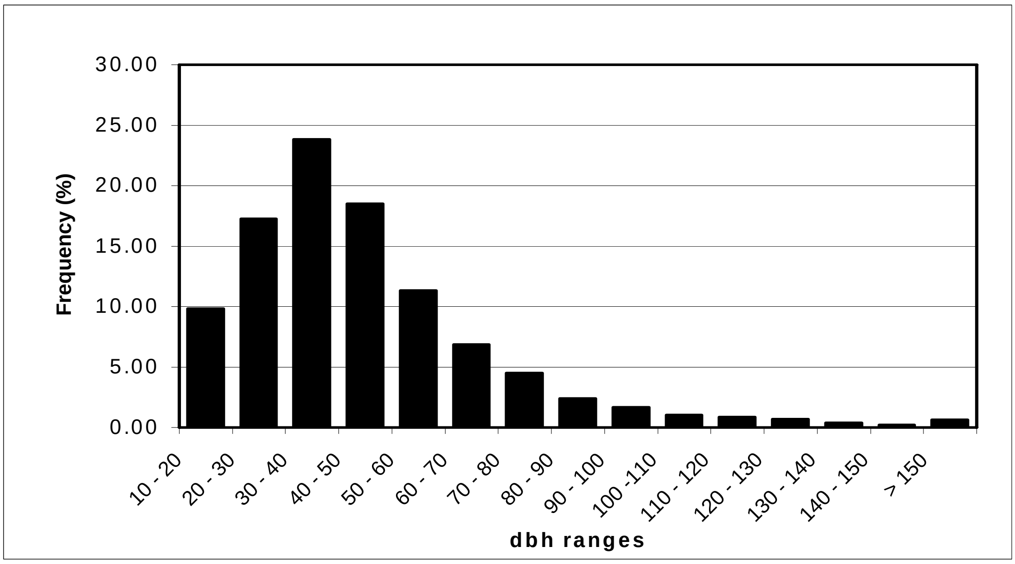

Figure 2. Frequency distribution (%) of diameters at breast height (in cm) of all trees found dispersed in pastures (n = 5,896 trees) of cattle farms in a dry tropical ecosystems in Cañas, Guanacaste, Costa Rica, 2002.

The frequency distributions of the diameters of timber tree species (data not shown) present similar patterns to that of the overall tree population, where the categories best represented are those in the range of 10 - 60 cm in dbh. Timber tree species with larger dbhs (> 100 cm) were represented by *E .cyclocarpum* (n = 29), *S. saman* (n = 18), *P. quinata* (n = 11) and *A. inermis* (n = 8). The most abundant timber tree species such as *T. rosea, C. alliodora and T. ochracea* had mean dbh`s of 35.60 $\pm$ 0.59, 39.55 $\pm$ 0.60 and 33.43 $\pm$ 0.88 cm, respectively.

Significant differences ($P < 0.001$) were found for the structural characteristics analyzed among the most dominant tree species (Table 2). *E. cyclocarpum* had significantly larger mean crown area, dbh and height ($P < 0.05$) than any other species in this group. Similarly, *S. saman* had larger crown area and height than the other species, but was significantly smaller than *E. cyclocarpum* ($P < 0.05$). *A. inermis* and *G. ulmifolia* had relatively larger crown areas. The most dominant species were *T. rosea, G. ulmifolia* and *A. aculeata* as they were present at much higher densities than the species of larger crown size (Table 2).

Table 2. Mean crown area and structural characteristics of the main individual tree species (n = 11) found dispersed in pastures of cattle farms in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2002. Data are organized in decreasing order of mean crown area.

Tree species	n	Crown area(m^2)		dbh (cm)		tree height(m)		Density (n ha^{-1})	CCP
Enterolobium cyclocarpum	29	481.7 g	(78.0)	92.6 g	(9.8)	15.9 h	(1.1)	0.03	2.6
Samanea saman	41	295.7 f	(40.7)	57.3 ef	(6.2)	14.2 g	(0.9)	0.05	2.3
Guazuma ulmifolia	337	141.6 e	(4.3)	58.9 ef	(1.6)	10.3 cd	(0.1)	0.40	8.9
Andira inermes	107	139.5 e	(7.5)	59.5 f	(2.2)	9.9 cd	(0.3)	0.13	2.8
Pachira quinata	51	117.5 d	(13.3)	53.7 de	(3.7)	12.1 e	(0.6)	0.06	1.1
Byrsonima crassifolia	192	99.2 cd	(3.9)	50.1 d	(1.4)	8.6 b	(0.1)	0.23	3.5
Tabebuia ochracea	144	94.6 c	(5.1)	33.5 ab	(1.3)	10.9 d	(0.3)	0.17	2.5
Cordia alliodora	316	89.0 c	(3.1)	42.8 c	(0.9)	13.1 f	(0.2)	0.38	5.2
Tabebuia rosea	467	61.7 b	(1.9)	36.5 b	(0.7)	10.6 cd	(0.2)	0.56	5.4
Bursera simaruba	22	43.0 b	(9.1)	30.2 a	(2.9)	6.7 a	(0.4)	0.03	0.2
Acrocomia aculeata	400	21.1 a	(1.0)	36.4 b	(0.6)	9.9 c	(0.2)	0.48	1.6

Density = Calculated as the number of individuals of the particular tree specie divided by total farm pasture area. CCP = crown cover expressed as percentage of total crown cover (Total crown cover = 53.6 ha). Means (standard errors) within a column with different letters are significantly different ($P < 0.05$) using Duncan test.

Crown cover (defined as the percent of the pasture that was directly under crowns) and tree density (trees ha^{-1}) showed a similar trend distribution within paddocks (Figure 3). Mean crown cover on paddocks was 7 % (SE $\pm$ 0.54) and mean tree density was 8.1 trees ha^{-1} (SE $\pm$ 0.66) with large variability among paddocks. Crown cover of individual paddocks varied from 0 to 49 % whereas tree density ranged from 0 – 70 trees ha^{-1}.

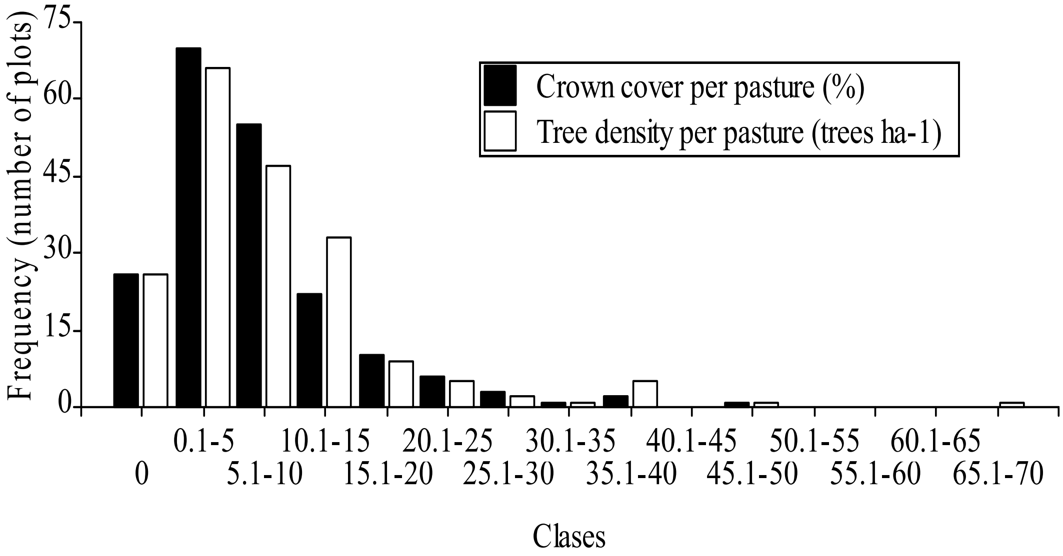

Figure 3. Frequency distribution table of crown cover (%) and tree density (trees ha^{-1}) of trees found dispersed in pastures of cattle farms inventoried (n = 196) in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica 2002.

The linear regression analysis models (Table 3) performed between the independent variables (paddock descriptors such as slope, size, pasture type, distances as well as tree characteristics like height and dbh) as a function of crown cover (%) and tree density (dependent variables) of paddocks (n = 196) were statistically significant ($P < 0.0001$; $r^2 > 0.25$) for both, crown cover (%) and tree density models (Appendix 2). Pasture crown cover (%) was influenced positively ($P < 0.05$) by paddock slope (%) and mean height (m) of dispersed trees within the paddock. On the other hand, tree density (trees ha^{-1}) was positively affected ($P < 0.05$) by paddock slope (%), mean height (m) of dispersed trees within the paddock and by the shortest distance (m) to internal farm roads and negatively by paddock size (ha) and mean dbh (cm) of dispersed trees in paddock.

Table 3. Regression models for crown cover (%) and tree density (tree ha^{-1}) of tree species found dispersed in pastures of cattle farms in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2002. Standard errors of regression parameters are present in parenthesis.

Estimated variable	Linear model	r^2	P < value
Crown cover (CC, %)	CC = 3.2 (3.7) + 0.27 (0.11) S + 0.86 (0.17) h	0.29	0.0001
Tree density (TD, n ha^{-1})	TD =9.15 (4.6) – 0.35 (0.17) Sz + 0.26 (0.13) S + 0.01 (0.002) D + 1.10 (0.21) h – 0.13 (0.04)dbh	0.26	0.0001

S = paddock slope (%); h = mean tree height (m); Sz = paddock size (ha); D = distance to farm internal road; dbh = diameter at breast height (cm).

Relationships between tree cover and farm type

Crown cover and tree density

Crown cover (m^2 ha^{-1}) of dispersed trees in pastures was almost three times higher on small beef cattle farms than on mixed farms (P < 0.05). On the other hand, even though small beef cattle farms had almost twice the crown cover of medium and large beef cattle farms, no significant differences (P > 0.05) were found among them. Crown cover from individual tree species was found to be similar between the four farm types (P = 0.15). But, results also show that mixed farm types maintain significantly (P < 0.05) lower crown cover from clustered trees in comparison to small beef cattle farms (Figure 4).

Small beef cattle farms had significantly higher tree density (trees ha^{-1}) than mixed farms and large beef cattle farms (P < 0.05), but not in comparison to medium beef cattle farms. When tree densities were divided into different tree use types (timber, forage, fruits) significant differences (P < 0.05) were found only for fruit tree density between small beef cattle farms and the other three farm types (Table 4).

Table 4. Mean crown (m^2 ha^{-1}) cover and tree density (tree ha^{-1}) of tree species found dispersed in pastures of cattle farms in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica 2002.

Variable	Mixed (n = 4)		Beef small (n = 4)		Beef medium (n = 5)		Beef large (n = 3)	
Crown cover (m^2 ha^{-1})								
Total	387 a	(190)	1096 b	(188)	701 ab	(143)	577 ab	(177)
Individual trees	223 a	(81.4)	614 a	(151)	370 a	(100)	343 a	(100)
Cluster trees	164 a	(62.7)	483 b	(71.2)	331 ab	(83.3)	234 ab	(83.4)
Tree density (tree ha^{-1})								
Total density	5.3 a	(2.3)	13.3 b	(2.3)	8.2 ab	(1.4)	6.5 a	(1.3)
Timber trees	1.9 a	(0.8)	5.6 a	(1.3)	4.2 a	(1.2)	3.6 a	(0.8)
Forage trees[#]	2.4 a	(0.6)	3.5 a	(1.5)	1.9 a	(0.6)	2.0 a	(0.7)
Fruit trees[&]	1.7 a	(0.3)	4.6 b	(0.8)	2.0 a	(0.7)	1.8 a	(0.4)

[#] Forage trees are those species which fruits or leaves are consumed by cattle. [&] Fruit bearing trees are those species classified as producing fruit for human consumption. Means (standard errors) within a row with different letters are significantly different ($P < 0.05$) using Duncan test.

The abundance curves for each farm type (Figure 4 a-d) showed that the twenty most abundant tree species were in general the same species in all farm types, although they varied in the order and number of individuals found. For example, *G. ulmifolia* was the most abundant tree species found dispersed in medium beef cattle farms and mixed farms. *C. alliodora* was the most abundant tree species found dispersed in pastures of small and large beef cattle farms. *T. rosea* was the second most abundant tree species found in the medium beef cattle farms but the third most abundant species on small and large beef cattle farms, whereas for mixed farms it occupied the fourth place. On the other hand, *A. panamensis* and *Lonchocarpus spp.* were not present in the mixed farm type while *G. sepium* was not present in medium beef farm types but the twenty most abundant tree species were present in small beef cattle farms. The species names can be found in Appendix 1.

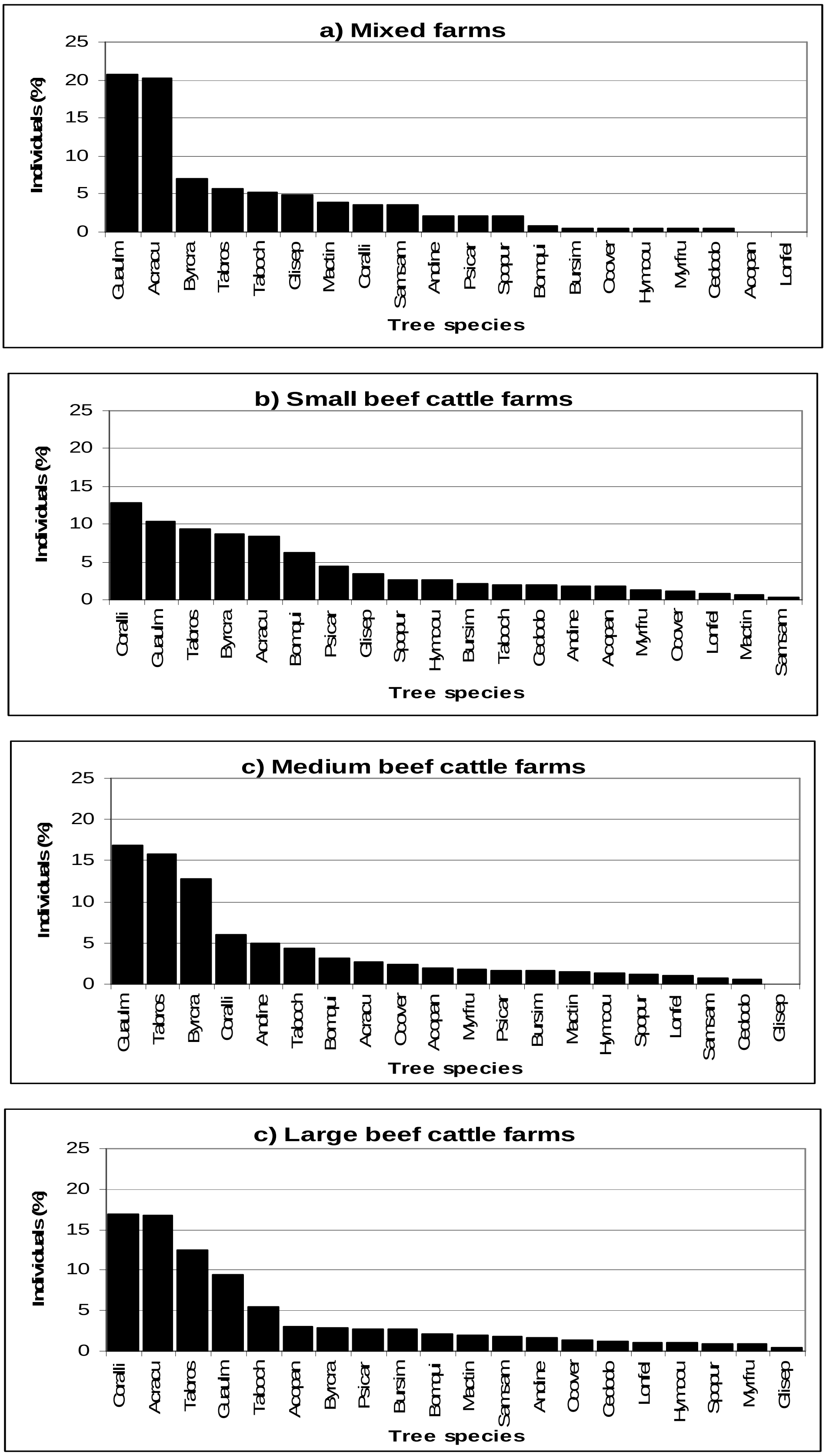

Figure 4. Species abundance curves of the twenty more abundant tree species found dispersed in a) mixed b) small beef c) medium beef and d) large beef cattle farms in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2002. Species names can be found in Appendix 1.

Biodiversity indices

The Jaccard similarity index for biodiversity (Table 5) divided the farms into two groups; one including the three types of beef cattle farms which had comparable similarity index among them (65%) regardless of their different sizes and the mixed farm type which had 44% of the same species as beef cattle farms. No statistical differences were found among farm types (P > 0.24) in mean values of species richness neither for the Simpson nor Shannon diversity indices (Table 6).

Table 5. Jaccard similarity matrix for the different cattle farm types in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2002.

Diversity indices	Beef small (n = 4)	Beef medium (n = 5)	Beef large (n = 3)	Mixed (n = 4)
Beef small	*	59.3407	65.5172	40.2597
Beef médium	*	*	65.1685	42.3077
Beef large	*	*	*	42.8571
Mixed	*	*	*	*

Table 6. Mean Shannon and Simpson diversity indices for the different cattle farm types in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2002.

Diversity indices	Mixed (n = 4)	Beef small (n = 4)	Beef medium (n = 5)	Beef large (n = 3)
Simpson	0.44^{a} (0.04)	0.66^{a} (0.01)	0.58^{a} (0.07)	0.60^{a} (0.01)
Shannon	0.91^{a} (0.04)	1.6^{a} (0.01)	1.4^{a} (0.07)	1.5^{a} (0.01)

Means (standard errors) within a row with different letters are significantly different (P < 0.05) using Duncan test.

Discussion

Dispersed trees in pastures

The results of this study as well as other studies conducted in different regions of Central America showed that dispersed trees in pastures are a general feature in cattle farms (Harvey and Haber 1999; Stokes 2001; Souza de Abreu *et al.* 2000; Cajas and Sinclair 2001; Harvey *et al.* 2005; Sanchez *et al.* 2005). Moreover, the study showed that the number of individuals trees, tree species richness, abundance and cover, expressed either as tree crown cover (m^2 ha^{-1}) or tree density (trees ha^{-1}), were irregular and heterogeneously distributed among paddocks. This large variability can be attributable to farm management (Villacis *et al*. 2003), specific paddock characteristics such as size and topography as well as to the particular importance gave by farmers to a specific tree species such as use, form, charactersitcs and health. (Muñoz *et al*. 2003; Villanueva *et al*. 2003a; Augusseau *et al*. 2005; Kosaka *et al*. 2006)

Dispersed trees in pastures showed an asymmetric dbh distribution where individuals were concentrated in the 20 to 60 cm dbh category (Figure 2). A low number of trees in the lowest dbh category (10 – 20 cm) indicated a low rate of natural regeneration which may be associated with pasture management practices such as weed control, grazing regimen and stocking rates. Recent studies in Costa Rica (Esparza) and in Nicaragua (Rivas), which have similar conditions to this study, show that the number of individual trees and species were higher in pastures in which manual weed control was practiced compared to pastures in which herbicides were applied (Camargo *et al*. 1999; Villanueva et al. 2003a). Tree seedling damage caused by cattle trampling, defoliation and breaking of young trees is another important factor that also affect tree richness and abundance of paddocks. Guevara *et al.* (2004) stated that when cattle were excluded from pastures remnant trees in pastures effectively favored the establishment of tree seedlings. Pastures managed in a very intensively manner (high stocking rates and heavy grazing regimens) had lower tree density and species compared to pastures managed less intensively (Villacis *et al*. 2003).

The sowing of grass species is another factor that affects the natural regeneration of dispersed trees in pastures. Villacis *et al*. (2003) found lower tree cover in pastures sown with improved tree species compared to those pastures sown with naturalized grass species. Thus, the fact that large areas of pastures in the study area were established with the aggressive improved *Brachiaria brizantha* grass species, may have caused competition between grass and tree seedlings which resulted in high sapling mortality, lowering natural regeneration rates of trees in pastures.

On the other hand, large individuals (with dbh > 100 cm) such as the valuable timber tree species *S. saman* and *E. cyclocarpum* were found at low abundances (< 1.5%). A possible reason for this could be that despite the large tree crowns of these tree species have (Table 2) which can reduce pasture growth to a larger exten than smaller tree crowns, the trees produce timber highly valued by farmers. In addition, there is a high demand for timber species in the region (Viera and Barrios 1998), to be used in the farm as well as for sale. Apparently farmers have been harvesting matured trees from pastures which may also explain the small number of individuals with large diameter. Studies conducted at Esparza, near the study zone, reported that timber volume extracted from these two tree species in conjunction with *Cedrela odorata* and *Pachira quinata* accounted for 83% (Viera and Barrios 1998) and in Cañas, and Rio Frio, farmers are using large trees for poles and timber in their farms (Villacis *et al*. 2003; Villanueva *et al*. 2003a).

The inventory results showed that trees were growing in clusters (46%) or in isolation in pastures (54%) and were distributed heterogeneously within the pastures. This pattern of tree configuration could have been caused by seed dispersal which plays an important role in regeneration and tree seedlings establishment. Dispersed trees in pastures have been shown to be good source for seed dispersal compared to open pasture areas (Nepstad *et al.* 1990) since trees serve as nesting, feeding, and roosting sites for a large variety of bird and bat species which are important seed dispersers underneath trees. As a consequence, higher propagation rates of native forest plants occur in pastures and over time, if allowed by farmers, clumping may occur as individuals expand and join together (Holl 1999a; Holl 1999b; Esquivel and Calles 2002; Teklehaimanot *et al.* 2002; Guevara *et al.* 2004).

Even though many tree species were counted, many were found in low abundances in pasturelands of cattle farms (Appendix 1). Sixty percent of total tree species were represented by less than 15 individuals. Twenty species were found to be represented only by one individual and seven species were represented by two individuals. The patterns of tree richness and abundance can be related to farmer strategies of combining different tree species based on their services, functions and structure. This can include the provision of shade, food for humans and wildlife from fruit bearing trees, forage for cattle from forage trees apart from their capacity to enhance soil fertility and the commercial value of timber trees from which farmers use to diversify their farm income sources (Beer *et al.* 2000). It also can be associated with a farmer’s decision to leave or remove tree species and individuals based on tree structural characteristics according to their needs and preferences in such a way that farmers are leaving in pastures trees with small crowns whereas large dbh trees are harvested. Local knowledge studies conducted in the same study zone (Stokes 2001; Muñoz *et al.* 2003) as well as farmers personal communication (Cañas 2002) show that farmers prefer to maintain large tree species, such as *E. cyclocarpum, S. saman, Ficus spp and Mangifera indica* at low densities in order to not interfere with pasture production but to provide fodder, shade and shelter to cattle, whereas the opposite was true for high valuable timber species such as *C. alliodora and T. rosea* which have small tree crown sizes

The low tree richness and abundance of some particular tree species such as, *Acacia farnesiana* (L.) Willd.; *Apeiba tibourbou Aubl*; and *Pocteria campechiana* could lead to the loss of some valuable tree species (Harvey and Haber 1999) for which conservation strategies must be considered. Farm characteristics of this study showed that many farms had small areas with secondary re-growths (charrales) and those species that are represented by small numbers in pastures may be planted in these areas. This implies that the strategy for conservation of trees on a farm level would have to be a combination of a mixture of tree speices in different habitats such as trees in pastures, live fences, riparian and secondary forests.

This study showed that tree density, abundance and crown cover of trees dispersed in pastures was low but with a high tree species richness including some endangered tree species. Thus, maintaining trees in cattle farm systems may represent a great opportunity to conserve diversity because of the large amount of pasturelands existing worldwide. Tree species in pastures should include a mixture of timber, firewood, fruits and forage sources from which farmers can increase farmr productivity wile provide habitats, nesting and roosting sites and fed source to silvester animals and birds within agricultural landscape contributing to conserve diversity. Despite the low mean tree density (8 trees ha^{-1}) and crown cover (7 %) found in this study, high variability in both variables was observed among paddocks. More than 70 % of paddocks inventoried had less than 10 trees per hectare and less than 10 % crown cover although some paddocks have larger densities and cover (Figure 3). Studies in the same study zone (Stokes 2001; Muñoz *et al.* 2003) as well as the regression analysis of this study suggests that the high variability of cover and density found among paddocks and the similar tree diversity among farm types could be related to farmer knowledge and preferences as well as to paddock and tree species characteristics. Local knowledge studies show that livestock farmers had a wealth of knowledge regarding how different tree species and cover affects the growth of pasture but did not have a good understanding of the improvements in cattle productivity by keeping trees in pastures. Based on this, they make decisions on how to manage natural regeneration and cover of trees in their pastures (Stokes 2001; Muñoz *et al.* 2003). The regression analysis of this study showed that less sloping paddocks were associated with lower tree densities and cover. These findings suggest that farmers were using the acquired local knowledge to manage the tree cover to protect the hilly areas against soil depletion and erosion. It may be also due to the fact that flatter areas are dominated with more fertile soil (vertisols) such that livestock production is more intensively managed on the more fertile flat areas were grasses may also maintain better cover suppressing natural regeneration of trees.

Richness, abundance, diversity, density and size of dispersed trees in pastures depend on several factors such as agroecological zones, farm size, pasture management and farmer's economic dependence on farm and tree products. Tree inventory from this study show that the five most abundant tree species dispersed in pastures are the same tree species found in pastures of cattle farms in Rivas Nicaragua but are different to those found in pastures of Rio Frio cattle farms in Costar Rica. This is not surprising since Cañas and Rivas are classified as dry tropical ecosystems and share the same agroecological conditions whereas Rio Frio belongs to another agroecological class (humid tropical ecosystem). In the same sense, tree density was higher in cattle farms in Rivas, Nicaragua than in Cañas Costa Rica but dbh of dispersed trees in pastures was higher in Cañas than in Nicaragua. Main reason for this is because Nicaragua farmers allow more natural regeneration to occur in their pastures in order to supply higher demand for tree products, especially firewood, since Nicaragua farmers are more economical depended on their farms than Costa Rica farmers are (Villanueva *et al*., 2004; Ibrahim 2006 personal comunication).

Relationship between tree cover and farm types

Beef cattle farms, regardless of size, maintained proportionally the same area under pastures (81%) whereas mixed farms, which are dedicated mainly to agriculture, had as a consequence, a smaller percentage of their land under pastures (49%) but similar tree diversity as beef cattle farms. The fact that similar tree diversity was found between different cattle farm systems can be attributable to the similar land use history, site conditions of farms as well as farmers criteria for selecting tree species that are useful to them and to the farm (Augusseau *et al*. 2005; Kosaka *et al*. 2006). On the contrary, crown cover, tree density and number of species within pastures were lower on mixed farms than on beef cattle farms. These differences could be explained by the fact that in mixed farms it is common to alternate land use from pasture to agriculture and normally trees interfering with plowing and crop yield are felled and farmers leave only tree species which are of relatively high importance to them (Hocking *et al*. 1997; Guevara *et al*. 1998).

A clear tendency occurred for small beef cattle farms to have higher tree densities and crown cover in pastures compared with larger beef farms (Table 4). The higher tree density and cover in small beef cattle farms could be due to the fact that pastures serve for a multifunctional role (Singh 1991; Devendra and Ibrahim 2004; Kindt *et al*. 2004) since small beef cattle farms do not have large land areas to plant trees and farmers are managing pastures in a more intensified and diversified manner increasing tree density to conserve tree species that are useful to the farm in order to diminish external risks of cattle enterprises. The higher densities and cover found in the small beef cattle farms are comparable with those reported by Guevara *et al*. (1998) in cattle farms in Veracruz, México in which they related tree density to farm size: large farms had lower tree density (2.2 trees ha^{-1}) than small farms (4.1 trees ha^{-1}). Similarly, when tree cover was classified according to tree main uses, timber trees were the most abundant trees found dispersed in pasturelands of beef cattle farms in Cañas. Similar results were found for dairy farms in San Carlos, Costa Rica (Souza de Abreu *et al*. 2000) and in dual purpose and beef cattle farms in Colombia (Cajas and Sinclair 2001) in which timber trees were the most abundant species.

Conclusion

This study shows that the crown cover (m^2 ha^{-1}) or density (trees ha^{-1}) of trees in pastures were low, irregular and heterogeneously distributed in pastures. Six tree species, *Tabebuia rosea*, *Guazuma ulmifolia*, *Cordia alliodora*, *Acrocomia aculeata*, *Byrsonima crassifolia* and *Tabebuia ochracea* accounted for 60% of total tree population inventoried in pastures, whereas many species were represented by only a few individuals. Therefore policy incentive schemes should be designed through a participatory approach with farmers to increase the population of tree species that are in risk to be lost and are usefull to farmers. Large variability of tree cover occurred within the same farms as well as across farms but Shannon and Simpson diversity index were found to be similar across different farm types. This is due mainly to the similar knowledge, preference and management that farmers have in their farms. Farmers tend to manage a diversity of trees dispersed in pastures at low densities to fulfill different farm needs. Thus, tree species with large crowns (i.e. *Samanea saman*, *Enterolobium cyclocarpum*) are maintained at low densities to avoid reducing pasture productivity while providing shade, shelter and fodder to cattle. Conversely, timber tree species with smaller crowns such as *C. alliodora*, and *T. rosea* are found at higher densities to obtain additional income source when it is needed. Tree species used for animal feeding (i.e. *G. ulmifolia*) are present in farms at high densities regardless of their dense crown type due to the contribution they make to cattle fodder. The higher crown cover (m^2 ha^{-1}) and density (trees ha^{-1}) of trees in pastures found in small beef cattle farms (< 50 ha) than larger beef cattle farms (> 51 ha) and mixed farms (beef and agriculture) suggest that small beef cattle farms are using pastures in a more intensified and diversified way.

CHAPTER IV

Impacts of dispersed trees in pastures on fodder quantity and quality to cattle in seasonally dry ecosystems

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Key words: *Acrocomia aculeata*, animal nutrition, *Brachiaria brizantha*, *Cordia alliodora*, crown cover, *Enterolobium cyclocarpum*, fruits, *Guazuma ulmifolia*, *Samanea saman*, silvopastoral systems, *Tabebuia Rosea*.

Abstract

Dispersed trees in pastures of cattle farms may influence cattle productivity both by affecting grass productivity and quality, and also by providing fruits to cattle. However, little is known about the productive roles that dispersed trees in pastures have on the availability and nutritive value of the overall feed availability (grass + fruit pods) to cattle. To address this gap, research was conducted with the objective of evaluating the impacts that different tree species dispersed in pastures have on forage availability and quality in the dry tropics of Costa Rica in 2003. Standing herbage biomass (SHB) harvested under the crown of isolated mature individual tree species was significantly ($P < 0.001$) lower than in open pasture areas for all tree species except that of *Acrocomia aculeata*, however, SHB quality, particularly crude protein content, was higher underneath tree canopies. Additionally, tree fruit pods collected in this study had higher *in vitro* dry matter digestibility (> 63%) and crude protein content (> 8%) than grasses. The results also show that, irrespective of the season a slight increase in SHB was observed at pasture level as crown cover increased from 0 to 16% followed by a decrease in biomass as crown cover increased above this percentage. It can be concluded that pastures could tolerate moderate (< 16%) crown cover of mixed tree species composition without suffering large declines in standing herbage biomass. The mixed tree assemblages found in pastures provides more stable fodder with higher nutritional values that are available to cattle during the dry season than monoculture pastures. These conditions resulted in improved animal production. The net effect of tree cover on forage productivity is a function of both, the tree species present and their densities.

Introduction

Livestock production has generally been based on the establishment of introduced grasses grown in monoculture as the main feeding source for cattle. Large areas of forest have been cleared to serve this purpose in tropical Latin America (Kaimowitz 1996). However, the productivity and sustainability of these systems where long seasonal dry periods (120 to 180 days year^{-1}) and frequent droughts occur have been low (Shelton 2004). In an attempt to revert this situation, the integration of trees in cattle farm systems is now being considered an essential necessity to favor cattle productivity (Pezo *et al*. 1999; Galindo *et al*. 2003). Shade trees have been shown to significantly improve animal productivity by reducing animal heat stress in tropical climates. In the Central American tropics, milking cows grazing moderately (10 > 20%) shaded pastures showed an increase of 9% in milk production in comparison to milking cows grazing in un-shaded pastures (Souza de Abreu *et al*. 1999) and a 29% increase in milk production in cows grazing in low (crown cover < 10%) shaded pastures (Betancourt *et al*. 2003). Similarly Zebu cattle grazeing moderately shaded paddocks in the dry tropics of Costa Rica have higher live weight gains in comparison to cattle grazing paddocks with low (< 10%) or high (>30%) shading (Restrepo *et al*. 2004). Traditional silvopastoral systems in seasonally dry areas are characterized with multi-purpose trees (eg. *Guazuma ulmifolia, Samanea saman, Enterolobium cyclocarpum, Leucaena leucocephala, Prosopis juliflora*) dispersed in pastures producing fodder and fruits of higher nutritive value than the associated grass species, especially during the dry season (Ortega *et al*. 1998; Aguilar and Condit 2001; Alvarez *et al*. 2003). The improved management of these systems can result in more cost-effective feeding strategies compared to farming system that use external supplements during the dry season to feed cattle.

Local knowledge (Stokes 2001; Muñoz *et al*. 2003) and decision making (Villanueva *et al*. 2003a; Leon 2006) studies with cattle farmers in Central America reveal that among the factors that influence farmers decisions in the retention of trees in pastures are tree species, crown size, density and the effects that they have on pasture productivity. Farmers prefer tree species that are of high timber value and those that have crowns that allow a relatively high percentage of light to penetrate to the understorey vegetation

(Muñoz *et al*. 2003). However, in seasonally dry areas there is an excess of grass production during the wet season and a deficit during the dry season (FAO 2000; Shelton 2004). Thus, understanding the trade-offs between how tree cover affects pasture production all year round and how trees contribute to provide fodder and fruits of high nutritional value during the dry season will help farmers to take better advantage of the tree cover. Apart from this, farmers can obtain additional benefits from trees such as timber, increased land value and environmental services payments (Pagiola *et al*. 2005).

Most of the studies on the effects of trees in pastures have been focused on measuring the quality and production of forage growing under shade of individual tree species and comparing it to that growing at full sun light (Belsky *et al*. 1989; Belsky *et al*. 1993a; Belsky *et al*. 1993b; East and Felker 1993; Durr and Rangel 2000). Other studies (Sibbald *et al*. 1991; Fernandez *et al*. 2002) have focused on how tree cover affects pasture and animal productivity in systematic silvopastoral systems (i.e forest/fruit plantations) but few studies have considered how tree cover from traditional silvopastoral systems affects the quality and production of pastures and on quantifying the production of fruits or pods of trees in these systems (Casasola 2001).

Traditional silvopastoral systems in Central America have 13 to 70 trees ha^{-1} and 9.8 to 49 % tree cover (Esquivel *et al*. 2003; Villanueva *et al*. 2003; Villacis *et al*. 2003). However there is little information on how increasing tree cover of paddocks affects farm productivity. This is key for determining threshold values of tree cover in pastures based on farmer's production objectives. Therefore, this study was conducted to a) determine the impacts of different levels of tree cover on standing herbage biomass, b) to quantify how individuals of contrasting tree species affect standing herbage biomass and quality of pastures, c) to quantify the amount and quality of fruits that these tree species produce during the dry season.

Methodology

Study site

The study was conducted between October 2002 and September 2003 in Cañas, Guanacaste, Costa Rica (10^{o} 11´ N and 84^{o}15´W). The area is classified as a tropical dry forest (Holdridge 1978) with elevations ranging from 60 to 250 masl (Arauz 2001). Annual rainfall ranges between 1000 to 2500 mm with > 95% falling from May to November. Average temperatures vary between 23 ºC and 31 ºC. Relative humidity fluctuates between 62 - 88 and 52 – 77% in the wet and dry seasons, respectively (Taboga Meteorological Station 2003). Soils in the lowlands are of volcanic origin and mainly vertisols with an average depth of 100 cm. In the uplands and slope areas soil are mainly inceptisols with rock formations on the soil surface. Soils are well drained, texture varies from fine to medium and fertility goes from medium to very high (Arauz 2001).

Previous characterization studies in the same study area (Esquivel *et al.* 2003; Villanueva *et al.* 2003) have shown that beef cattle production is the primary agricultural land use and is based mainly on Zebu (*Bos indicus*) breeds. Many cattle farmers are involved in converting paddocks of H*yparrhenia rufa* to *Brachiaria brizantha* in order to increase productivity. The later represent nearly 55% of the total study area. Based on these trends in pasture conversion, it was decided to assess the relationships between dispersed trees on *B. brizantha* pastures and forage availability and quality in a seasonally dry ecosystem in Costa Rica.

Brachiaria brizantha paddocks were characterized by mixed species assemblages of trees with different crown characteristics and fruit phenologies. The number of tree species within paddocks ranged from 0 to 17, tree density varied from 0 to 68 trees ha^{-1} , basal area varied from 0 to 15.7 m^{-2} and crown cover ranged from 0 to 36%. Paddock size ranged from 1.2 to 7.5 ha (Esquivel *et al.* 2003). In the dry season, paddocks were continuously grazed at an average stocking rate (SR) of 1.2 head ha^{-1}. During the wet season, paddocks were rotationally grazed with 4 to 30 day grazing periods and 30 to 50 days resting. The SR during the wet season ranged from 1.1 to 1.3 head ha^{-1} (C. Villanueva. pers comm. 2006).

Experimental layout

From all the *B. brizantha* paddocks (n = 60) available in 16 cattle farms, a total of 13 paddocks were selected using a stratified sampling scheme reflecting the entire range of crown cover percentage distribution (0–36%) found in pastures of cattle farming systems (Esquivel *et al.* 2003). Selected paddocks were used in three studies. The first study determined the effects of tree crown cover on standing herbage biomass (SHB) and botanical composition at pasture level. In the second study were evaluated the effects of four multipurpose tree species (*Enterolobium cyclocarpum* (Guanacaste), *Guazuma ulmifolia* (guacimo), *Acrocomia aculeata* (coyol) and *Samanea saman* (genizaro) and two timber tree species (*Cordia alliodora* (laurel) and *Tabebuia Rosea* (roble)) on SHB and quality under and outside the canopy of each tree species. In the third study was quantified the amount and nutritional quality of tree pods produced by the four multipurpose tree species.

Relationships between crown cover and standing herbage biomass at pasture level

Within each selected paddock (n = 13), SHB measurements were taken 21 $\pm$ 5 days after Zebu cattle had been moved out of the paddock to allow pasture recovery. Measurements were performed once during the early dry period (December 2002 and January 2003), once during the late dry period (March and April 2003), and once during the early rainy period (June and July, 2003). Paddock SHB and botanical composition were assessed using the BOTANAL technique (Tothill *et al.* 1978). Each paddock was surveyed by walking the entire area to observe the pattern and distribution of the vegetation in terms of standing herbage biomass availability and botanical composition. Once this exercise was completed five quadrates (0.5 x 0.5 m) were used to establish a visual standard of SHB from 1 to 5 based on the SHB availability observed earlier; where 1 represented the lowest yield and 5 the highest (t'Mannetje, 2000). Each standard (n = 5) was replicated three times accounting for a total of 15 quadrates per paddock. Once the standards had been established, in each paddock a quadrate was used to systematically make 120 visual observations of the SHB which were ranked against the standards. The botanical composition in each of the visual observations was estimated visually in terms of the proportional area that is covered by sown grass, weeds and bare soil. After completing the 120 observations in each paddock, the standards (n=15) of each paddock were cut at the ground level, weighed in the field and oven dried at 60 ºC for 48 hrs to obtain dry matter (DM) content.

Effects of individual tree species on SHB and quality

Tree species selection

Previous tree inventory data (Esquivel *et al.* 2003) were used to select the four most abundant tree species dispersed in pastures: *Acrocomia aculeata* (coyol), *Cordia alliodora* (laurel), *Guazuma ulmifolia* (Guacimo) and *Tabebuia rosea* (roble). However, the tree inventory showed that the presence of these four species varied greatly between paddocks (some paddocks did not have any isolated individuals from a particular tree species selected). Therefore, four *B. brizantha* paddocks were selected based on the presence of at least three out of the four species. Additionally, with the purpose to include in the study large crown leguminous tree species that produce large quantities of high quality edible pods in the dry season that are regularly eaten by cattle, the multipurpose trees *Enterolobium cyclocarpum* (Guanacaste) and *Samanea saman* (genizaro) trees contained in the four selected paddocks were also included. This approach resulted in an unbalanced tree species distribution within the paddocks. Thus, the effects of six isolated tree species, coyol (n = 9), guacimo (n = 9), genizaro (n = 3), Guanacaste (n = 6), laurel (n = 12) and roble (n = 12) on SHB and quality were evaluated under and outside the canopy (n = 3 in each site) from each species. Samples were taken once during the early dry period (December 2002 and January 2003), once during the late dry period (March and April 2003) and once during the early rainy period (June and July, 2003). There were only a few adults of genizaro and Guanacaste trees within the paddocks and for this reason measurements were taken on only three individuals for genizaro and six individuals of Guanacaste.

Tree structural characteristics measurements

Individual trees of the selected species within each paddock were randomly selected. For each individual tree, the diameter at breast height (dbh), total tree height, bole tree height and crown cover were measured directly in the field. The dbh was measured with a diametric tape and expressed in centimeters. Tree heights were measured with a hand-held laser instrument (Impulse 200 LR), which calculates the height in meters based on sensor readings of distances and vertical angle measurements. Crown cover was measured from the readings of two perpendicular measurements covering the longest axes of the crown (Below and Nair, 2003).

Standing herbage biomass sampling

In order to quantify the amount and quality of SHB growing under tree canopies and compare to that growing at full sun light, SHB was sampled in three quadrates (0.5 x 0.5 m; t`Mannetje, 2000) randomly placed under canopy and three quadrates outside canopy by cutting the vegetation to ground level and weighing in the field. Afterwards, the three collected samples from each zone were mixed to form a composite sample according to treatment and a sub-sample of forage material of approximately 200 g was oven dried at 65 °C for 48 h to obtain dry matter (DM) content. A sub-sample (50 g) of each sample was taken to analyze their nutritional quality. Nutritional quality was analyzed for crude protein (CP) (micro Kjeldahl, Bateman 1970), *in vitro* dry matter digestibility (IVDMD; Tilley and Terry 1963) and neutral detergent fiber (NDF) (Van Soest 1985). Additionally, SHB botanical composition outside the tree canopy as well as under the canopy of each selected tree species within the paddocks was visually estimated by recording the percentage of sown grass, weeds and bare soil contained within each quadrate.

Light transmission measurements

To measure the amount of light reaching the area underneath the tree canopy from different species and relate them to SHB availability, light transmission (total and below canopy PAR) was measured between 12:00 and 14:00 h once before each SHB sample period (December and January 2002, March – April 2003 and June – July 2003) in a paired sample scheme with a 1 m long sunscan probe (Delta T Device, UK) pointing it at a random compass orientation. The paired sample scheme consisted of placing the sunscan probe outside the canopy at 1 m height to record total PAR readings and immediately after placing the probe at each interception point of a 3 x 3 m grid placed under the canopy of the selected trees to record the distribution and variation of PAR under the canopy. The number of readings under the canopy varied from 5 to 40 depending on the tree crown size, whereas for outside the canopy 5 PAR readings were recorded around the tree. For each tree, a mean value of the incident light reaching each zone was calculated by averaging individual readings provided by the sensor within the sun-scanner. The amount of PAR transmitted through the canopy to understorey vegetation is expressed in % and it is calculated as (PAR Shaded / PAR Open * 100).

Fruit production and quality

This study quantified the production and nutritional quality of fruits consumed by cattle for four tree species found in these systems. During the 2003 fruit production season (January – May), fruits of coyol, Guanacaste, guacimo and genizaro trees were collected as they fell to the ground to determine the quantity and quality of fruits available to cattle during the dry season. Seven trees of each of the four species (n = 28 total) available within the previous *B. brizantha* paddocks (n = 13) were selected based on accessibility to paddocks, trees and permission of farmers to collect the fruits. Each tree was fenced around with barbed wire (3 m outside of the canopy) to prevent cattle from consuming the fruits. All fallen fruits of each selected tree were collected weekly and weighed until fruit production stopped. Subsequently, fruits of each tree species collected during the same week were bulked and a sub-sample of approximately 200 g was sent to the laboratory to obtain DM, CP, IVDMD and NDF with the same techniques used for SHB.

Data analysis

Individual regression analyses were performed for each season to describe the relationships between crown cover (%) of paddocks and SHB (DM ha^{-1}) at pasture level. One way analysis of variance was performed to test differences between tree structural characteristics of the individual tree species. PAR under tree canopies, SHB and quality under and outside tree canopies were analyzed using a repeated measurement approach with an unbalanced randomized blocks in a split plot design using ANOVA, where paddock (n = 4) was considered as blocks, tree species (n = 6) was the main plot and season (n = 3) was considered the subplot factor. Comparisons between treatments means were compared by Duncan multiple range test. Means of SHB and quality between sampling zones (under and outside canopy) for each tree species and season were compared using paired "t" tests. Fruit production and quality were analyzed using a random complete design ANOVA where tree species (n = 4) were the treatments and individual were the replicates. The Duncan multiple range test was applied to test means differences (Steel and Torrie 1980). All data were checked for normality and variance homogeneity using Shapiro-Wills and Levene test, respectively. Only square root transformations were applied for fresh fruit production. All analyses were performed using InfoStat 4.1 (2004).

Results

Relationships between crown cover and standing herbage biomass

Irrespective of the season, standing herbage biomass increased in paddocks with tree cover between 0- 15% and then decrease when tree crown cover was > 20 % (Figure 1).

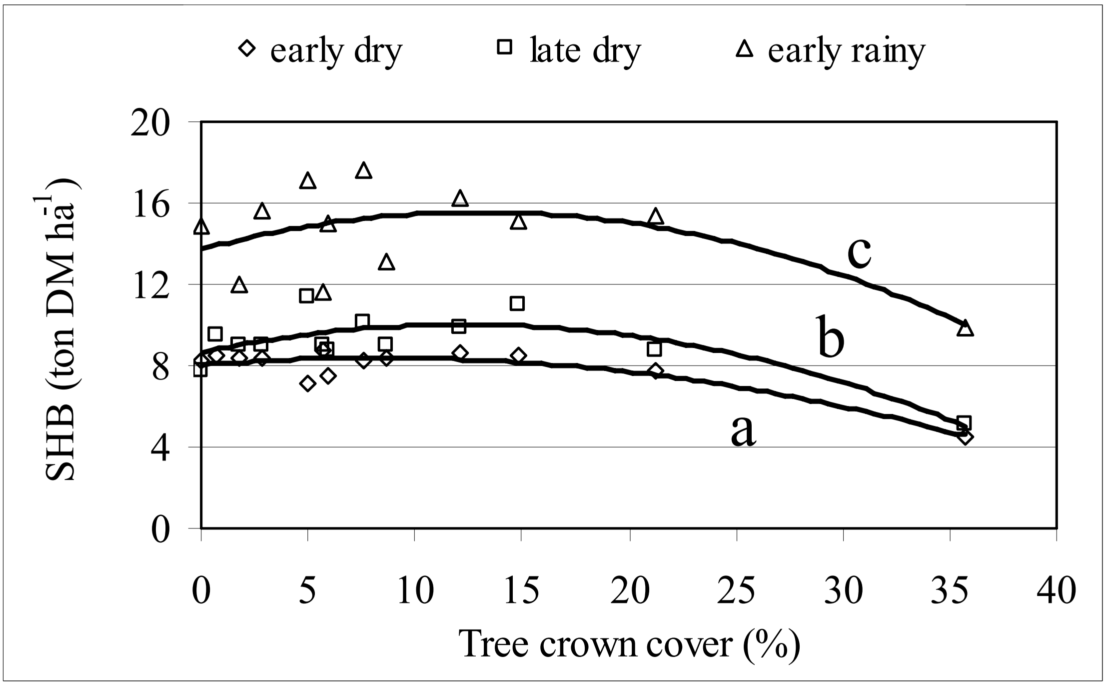

Figure 1. Relationship between percentage tree crown cover and standing herbage biomass (SHB t DM ha^{-1}) of paddocks at a) early dry (December 2002 and January 2003); b) late dry (March and April 2003) and c) early rainy periods (June and July, 2003)in *Brachiaria brizantha* pasture plots in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003.

The regression analysis showed that there was a significant ($P < 0.006$) quadratic relationship between SHB (y, kg DM/ha) and crown cover of trees (%, x) for measurements taken in the early and late dry season. In the early rainy season, although a similar trend was observed, the regression was only significant at $P = 0.08$ but with a low regression value compared with the dry periods (Table 1).

Table 1. Regression equations of standing herbage biomass (SHB, y t DM ha^{-1}) as a function of the percent of pasture covered by tree crown cover (x %) for measurements taken in the early and late dry and early rainy periods in *Brachiaria brizantha* pastures with tree species in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003.

Sampled period	Equation	R^2	P < value
Early dry	$Y = 8.0 + 0.08\,x – 0.005\,x^2$	0.80	0.006
Late dry	$Y = 8.6 + 0.22\,x - 0.01\,x^2$	0.70	0.004
Early rainy	$Y = 13.7 + 0.28\,x - 0.01\,x^2$	0.41	0.08

Botanical composition of paddocks (data not shown) with low to moderate tree crown cover (< 20%) were covered with the sown improved grass *Brachiaria brizantha* which represented between 90 to 95% of the botanical composition of these paddocks. On the other hand, those paddocks which had relatively high tree crown cover (> 30%) had a lower percentage (65 to 75%) of *B. brizantha* and a relatively high percentage of weeds (25 to 35%).

Effects of the individual tree species

Tree species characteristics

Of the six species studied, Guanacaste had the largest mean crown cover while coyol had the smallest. Genizaro had the second largest mean crown cover, which was significantly larger than guacimo, laurel, roble and coyol. Mean diameter at breast height and total height of Guanacaste trees were larger than for the other species, whereas mean bole height was similar among all species (Table 2).

Table 2. Mean structural variables for each of the six isolated tree species found dispersed in *Brachiaria brizantha* pasture plots in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003.

Species	n	dbh (SE) (cm)	Height (SE) Total (m)	Bole$^{\varphi}$ (m)	CC$^{\$}$ (m^2 $tree^{-1}$)	PAR (%, SE) Transmitted
coyol	9	36.4 (1.6) a	9.8 (0.5) a	na	19.5 (1.2) a	60.5 (6.0) c
genizaro	3	53.1 (2.3) b	13.3 (0.6) b	2.8(0.2) a	281.3(27.1) d	49.4 (2.4) b
guacimo	9	60.1(5.5) b	11.5(0.7) ab	2.3(0.2) a	169.9(22.0) c	33.7 (6.8) a
Guanacaste	6	91.8 23.4) c	18.0 (1.0) c	3.8(1.6) a	622.3(110.7)e	27.1 (4.6) a
laurel	12	29.9 (3.2) a	11.0 1.0) ab	2.7(0.2) a	65.4 (11.9) ab	64.4 (4.6) c
roble	12	34.2 (4.1) a	9.4 (0.5) a	2.5 (0.1) a	77.7 (10.1) b	54.9 (4.3) bc

dbh = Diameter at breast height; $^{\varphi}$ = height to the crown; CC$^{\$}$ = Crown cover measured from the readings of two perpendicular measures covering the longest axes of the crown; PAR = Photosynthetic active radiation expressed as percentage of full sunlight. Means (standard errors) with different letters within the same column are significantly different (P < 0.05) using Duncan test.

Light transmission

Significant differences were observed between species (P = 0.0002) and seasons (P < 0.008; data not shown) for the percentage of PAR transmitted under the canopy (Table 2) but PAR levels obtained under all species were consistent through seasons since the interaction species x season was not significant (P = 0.98). Higher PAR readings (> 50%) were taken under the canopies of coyol, laurel and roble in all seasons compared to the other species. On the contrary, Guanacaste and guacimo were the species which transmitted significantly (P < 0.05) lower PAR (21.7 and 33.7% respectively) under their canopies in all seasons. Mean PAR levels under the canopies across species were significantly (P < 0.05) higher during the early and late dry periods compared to the early rainy period for all tree species. Maximum PAR values in the early rainy period were around 50% of that of full sunlight for laurel and coyol, around 40% for roble and genizaro and around 20% for Guanacaste and guacimo.

Standing HB availability

Standing herbage biomass harvested underneath tree canopies was significantly (P < 0.05) higher under the genizaro, roble, laurel and coyol canopies than under guacimo and Guanacaste. The lowest value was obtained under the Guanacaste canopy, which was 41% lower than guacimo and around 70% lower than the other species. Standing herbage biomass under canopies of trees (shaded) was significantly (P = 0.08) lower than outside canopies (open) for all species except for coyol which had 12% less DM ha^{-1} under the canopy when compared to that measured in open pasture (Table 3).

Table 3. Mean standing herbage biomass (g DM m^{-2}) harvested in open zones and underneath isolated tree crowns of six species growing in *Brachiaria brizantha* pasture plots in a dry tropical ecosystem in Cañas, Guanacaste Costa Rica, 2003.

		Biomass in sampled zone			Sampled zone effect	
Species	n	% PAR transmitted	Open (SE)	Shaded (SE)	Difference# (%)	P value
coyol	9	60.6	562.0 (53.9) a	494.7 (65.6) b	88	0.14
genizaro	3	49.4	608.3 (105.7)a	423.3 (69.2) b	70	0.08
guacimo	9	33.7	597.1(58.2) a	223.7 (56.8) a	38	0.001
Guanacaste	6	27.1	548.4 (65.6) a	132.4 (79.4) a	23	0.002
laurel	12	64.4	603.0 (45.8) a	440.8 (45.3) b	73	0.005
roble	12	54.9	594.0 (35.9) a	463.3 (37.7) b	78	0.001
Mean		**51.6**	**587.2 (20.9)**	**384.9 (28.1)**	**65**	**0.001**

Amount of PAR transmitted through the canopy to understorey vegetation expressed in % and calculated as (PAR Shaded / PAR Open*100); P values refer to effect of zone (Open vs. shaded) compared by paired "t" test; Means (standard errors) with different letters within the same column are significantly different (P < 0.05) using Duncan test. Difference# Biomass under trees as a percentage of that found in the open zones.

The SHB outside as well as under the canopy of all species was significantly lower (P < 0.05) during the late dry period than early dry and early rainy periods. Mean SHB outside the canopy was consistent and significantly higher (29 to 34%) than that under the canopy at all seasons (Figure 2; P < 0.002), and the species x season interaction was not significant (P = 0.98).

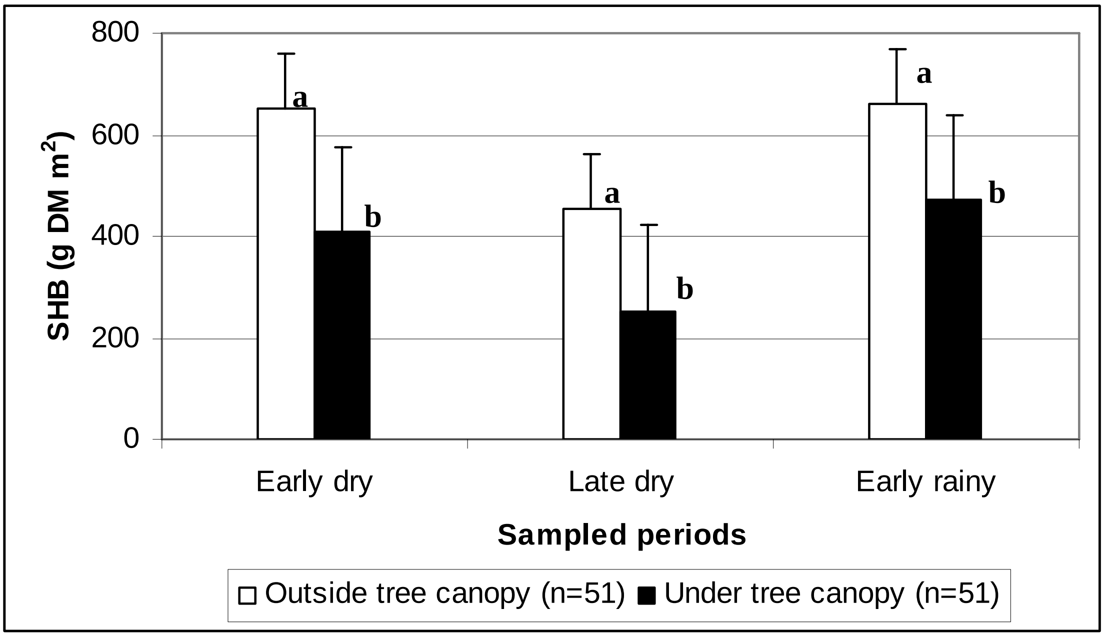

Figure 2. Mean standing herbage biomass (g DM m^{-2}) harvested in each season in open zones and underneath tree crowns for six tree species (n=51 trees total) found dispersed in *Brachiaria brizantha* pasture plots in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003. Bars with a different letter within a season indicate significant differences (P < 0.002) using paired "t" test.

Botanical composition

Pasture vegetation outside canopies of all tree species as well as under the canopies of coyol, laurel and roble was dominated by *B. brizantha* grass species, which accounted for more than 90% of the area. In contrast, the area under the crown of Guanacaste trees was dominated by bare soil (> 90%) with small percentages of the weed which is commonly named Panza de burro (*Triunfetta semitriloba*). There was a high percentage (10 to 65) of bare soil under guacimo crowns and the vegetation was dominated by a mixture of weeds such as *Richardia spp* and *Triunfetta semitriloba* (Figure 3).

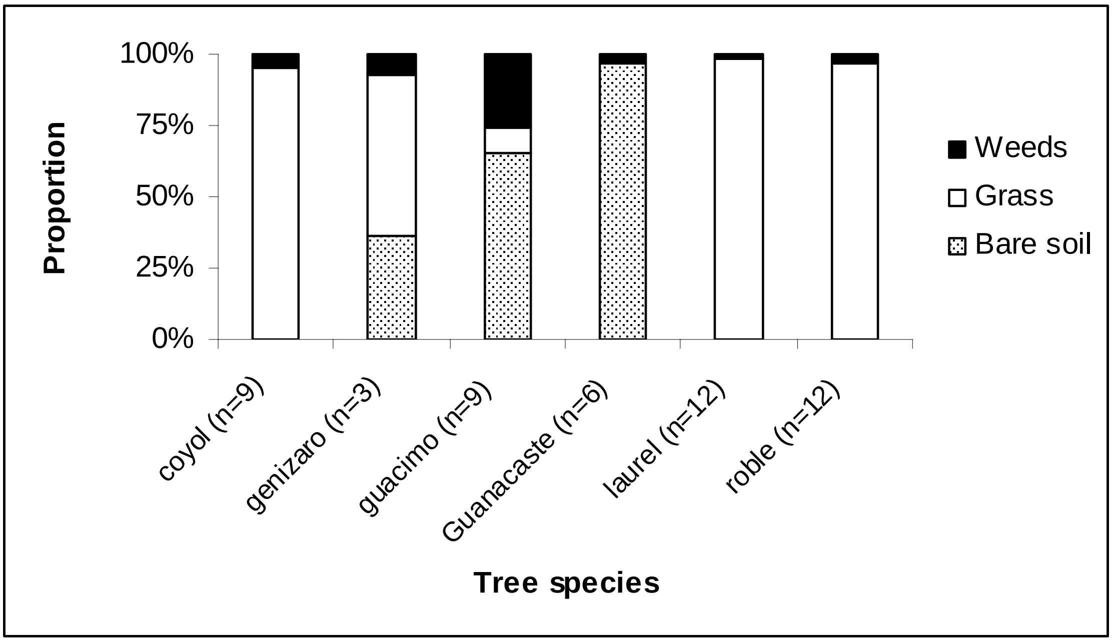

Figure 3. Mean percent weeds, sown grass and bare soil visually estimated in quadrants placed underneath tree crowns of six tree species found dispersed in *Brachiaria brizantha* pasture plots in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003.

Quality of SHB

The SHB under the Guanacaste canopies had significantly higher CP content than the other species ($P < 0.05$). Similarly, CP of SHB under the canopies of guacimo and genizaro was significantly higher than underneath coyol, laurel and roble ($P < 0.05$). The CP of SHB under the canopies of all tree species was consistently higher ($P < 0.05$) than that outside the canopies although highest differences were observed for Guanacaste (128%) and genizaro (67%), which are leguminous species (Table 4).

In vitro dry matter digestibility (IVDMD) of SHB was significantly higher ($P < 0.05$) under genizaro canopies than that under Guanacaste and guacimo canopies. The lowest IVDMD ($P < 0.05$) was found under the canopies of Guanacaste. *In vitro* DMD was also significantly different ($P < 0.05$) between sampling zones for all species except that of genizaro and roble. The SHB under canopy of coyol and laurel had significantly higher IVDMD values than outside tree canopies. On the other hand, SHB under the canopies of guacimo and Guanacaste had significantly lower IVDMD values compared to outside the canopy.

Neutral detergent fiber (Table 4) was significantly lower (P < 0.05) under the canopy of guacimo than under canopies of the other species. When comparing NDF between sampling zones, NDF was significantly lower under the canopies of guacimo (P = 0.01) and Guanacaste (P = 0.07) than outside the canopies.

Table 4. Mean crude protein (CP%), *in vitro* dry matter digestibility (IVDMD%) and neutral detergent fiber (NDF%) of the standing herbage biomass (g DM m^{-2}) harvested in open zones and underneath tree crowns of six species growing isolated in *Brachiaria brizantha* pasture plots in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003.

		Sampled zone		Sampled zone effect	
Species	n	Open	Shaded	Difference# (%)	P value
			CP (%)		
coyol	9	4.9 (0.6) a	6.1 (0.8) a	25	0.04
genizaro	3	4.6 (0.8) a	7.7 (1.2) b	67	0.05
guacimo	9	5.5 (0.5) a	7.7 (1.0) b	40	0.05
Guanacaste	6	5.3 (0.8) a	12.1 (1.3)c	128	0.05
laurel	12	4.6 (0.5) a	5.7 (0.6) a	24	0.004
roble	12	4.6 (0.5) a	5.9 (0.5) a	28	0.001
Mean		4.9 (0.2)	6.7 (0.4)	37	0.0001
			IVDMD (%)		
coyol	9	46.1 (1.5) a	47.9 (1.5) bc	4	0.01
genizaro	3	49.1 (2.1) a	48.9 (1.1) c	-0.4	0.88
guacimo	9	47.1 (1.7) a	43.1 (2.1) b	-8.5	0.05
Guanacaste	6	45.8 (1.7) a	35.3 (3.6) a	-23	0.01
laurel	12	44.8 (1.4) a	47.5 (1.2) bc	6	0.003
roble	12	46.0 (1.3) a	47.5 (1.1) bc	3	0.16
Mean		46.1 (0.6)	46.1 (0.8)	0	0.89
			NDF (%)		
coyol	9	79.2 (1.2) a	79.3 (1.0) b	0.1	0.89
genizaro	3	81.8 (2.1) a	78.5 (1.0) b	-4	0.19
guacimo	9	79.3 (0.8) a	58.6 (6.6) a	-28	0.01
Guanacaste	6	81.9 (2.7) a	74.4 (0.5) b	-8.	0.07
laurel	12	80.5 (0.9) a	80.0 (0.7) b	0.5	0.39
roble	12	80.2 (0.6) a	79.9 (0.5) b	0.3	0.57
Mean		80.2 (0.5)	75.4 (1.7)	6.0	0.01

= calculated as 100 – (shaded/open)*100; Means (standard errors) with different letters within the same column are significantly different (P < 0.05) using Duncan test. Difference# Biomass under trees as a percentage of that found in the open zones.

Mean CP of SHB (Figure 4) under and outside the canopy was significantly higher (P < 0.05) in the early rainy period compared to the other two periods, but no significant differences (P < 0.05) occurred between the early and late dry periods. *In vitro* DMD (Figure 5) of the SHB outside the canopy was significantly lower (P < 0.05) in the late dry period (42.9%) when compared to the other two periods (47.1 and 48.3% for early dry and rainy seasons, respectively). For samples harvested under tree canopies, IVDMD was significantly different (P < 0.05) between all seasons being 45.2, 42.8 and 49.2% for early dry, late dry and early rainy season respectively. Neutral detergent fiber of SHB outside the canopy was significantly higher (P < 0.05) in the late dry period (83.3%) compared to early dry (78.6%) and early rainy (78.5%) seasons. However, NDF of SHB harvested under the canopy was not significantly different (P = 0.85) between seasons. Comparisons between sampling zones within each season were significantly different (P < 0.03) for mean CP in all seasons (Figure 4) and for NDF at the late dry season (P = 0.09) whereas no significant differences (P < 0.05) were observed for the mean IVDMD in any season and NDF (data not shown) at early dry and rainy season.

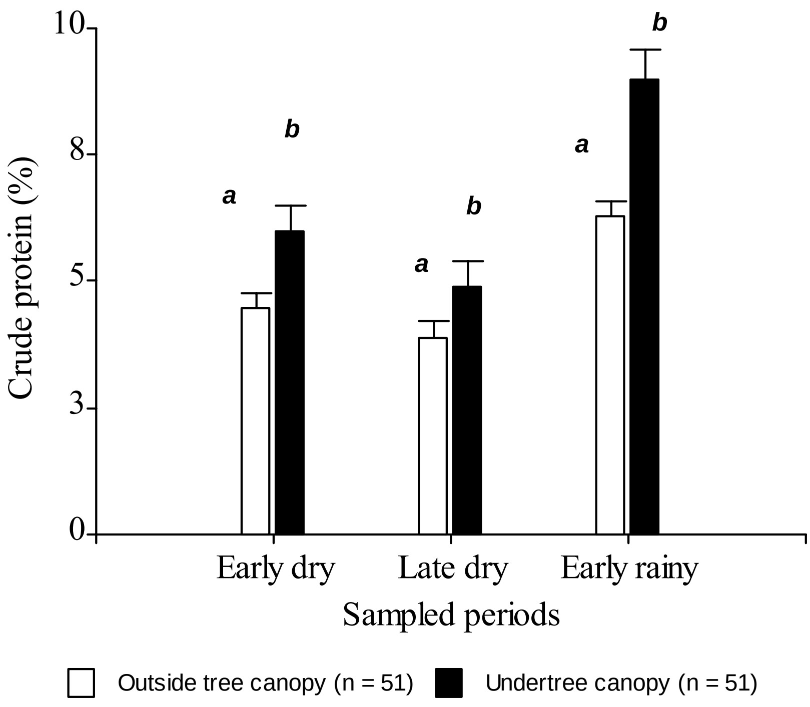

Figure 4. Mean crude protein percentage of standing herbage biomass at open zones and underneath tree crowns of six tree species growing isolated in *Brachiaria brizantha* pasture plots in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003. Bars with a different letter within seasons indicate significant differences (P < 0.03) using paired "t" test.

Fruit production

Fruit collection of the four multipurpose (Guanacaste, genizaro, guacimo and coyol) tree species (n = 7 per species) lasted from January 27 to May 12, 2003. During this period of time, the production of fruits of coyol was consisten through time whereas higher percentage of fruits of guacimo were produced during the early dry season (February) and that of Genizaro and Guanacaste during the mid dry (March) and end of dry season (April) respectively (Figure 5). Mean total fresh fruit production (kg $tree^{-1}$) was 3 to 10 times higher ($P < 0.05$) for Guanacaste trees than for the amount of fruit collected from the other tree species.

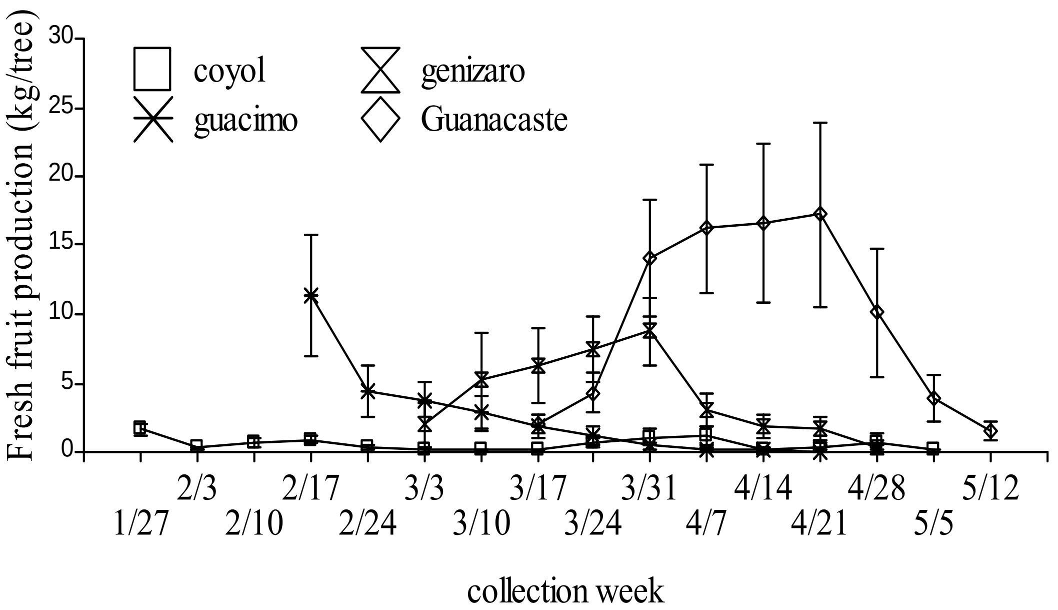

Figure 5. Mean weekly fresh fruit production (kg $tree^{-1}$) from January to May 2003 of four multipurpose tree species (n = 7 trees $species^{-1}$) growing isolated in *Brachiaria brizantha* pastures in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003. Vertical lines represent standard errors.

Guacimo and genizaro produced 3 to 4 times more fruits ($P < 0.05$) than coyol on a seasonal basis (Table 5). Mean total fresh fruit production by crown area (m^2) was similar across tree species except for coyol ($P < 0.05$). Fresh fruit production per m^2 $tree^{-1}$ for genizaro, guacimo, Guanacaste and coyol was 0.10, 0.12, 0.15 and 1.35 kg respectively.

Table 5. Mean accumulated fresh fruit production (kg tree^{-1}) during the production and collection period (16 weeks) of four isolated multipurpose tree species growing isolated in *Brachiaria brizantha* pasture plots in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003.

Species	n	Fruit production period (weeks)	Total fresh fruit production (kg tree^{-1})	Weekly Fresh fruit production (kg tree^{-1})	
				Production period[#]	Collection period[&]
Coyol	7	15 (8-15)	8.6 (2.7) a	0.6 (0.18) a	0.6 (0.17) a
Guacimo	7	10 (7-10)	26.4 (7.7) ab	2.6 (0.77) ab	1.7 (0.48) ab
Genizaro	7	9 (5-9)	36.1 (8.1) b	4.0 (0.90) b	2.3 (0.51) b
Guanacaste	7	9 (6-9)	86.0 (23.0) c	9.6 (2.56) c	5.4 (1.44) c

[#] Production period refers to the time in which each species was producing fruits. [&]Collection period refers to the total time (16 weeks) during which fruit was collected. Means (standard errors) in the same column with different letters are significantly different (P < 0.05) using Duncan test.

Fruit quality

The CP concentration of fruits of the leguminous trees (genizaro and Guanacaste) was significantly higher ($P < 0.05$) than that of the non-leguminous tree species (coyol and guacimo). Genizaro produced fruits with higher CP followed by Guanacaste, guacimo and coyol, respectively. Fruits of the leguminous tree genizaro also had higher IVDMD than the other species and significantly lower NDF than the non-leguminous trees but similar to that of Guanacaste. In contrast, coyol fruits had the lowest nutritive value. (Table 6)

Table 6. Mean dry matter (DM%), crude protein (CP%), *In vitro* dry matter digestibility (IVDMD%) and Neutral detergent fiber (NDF%) of fruits of four isolated multipurpose tree species growing isolated in *Brachiaria brizantha* pastures plots and of the grass (*B. brizantha*) in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003.

Species	n	DM (%)	CP %	IVDMD %	NDF %
coyol	7	80.5 (2.7) a	5.5 (0.2) a	66.4 (1.2) ab	42.4 (1.7) c
guacimo	7	83.3 (0.9) a	7.5 (0.5) b	63.3 (3.4) a	36.3 (3.8) bc
genizaro	7	81.9 (1.3) a	15.6 (0.3) d	71.1 (1.0) b	24.7 (2.9) a
Guanacaste	7	86.5 (1.0) a	13.1 (0.4) c	67.8 (0.9) ab	29.3 (1.4) ab
B. brizantha	**51**	**58.0**	**4.9 (0.2)**	**46.2 (0.7)**	**80.2 (1.2)**

Means (standard errors) in the same column with different letters are significantly different (P < 0.05) using Duncan test.

Discussion

Standing herbage biomass

The results obtained in this study showed that higher SHB was harvested at the rainy season than that at the dry season. It also showed that irrespective of the season, SHB at the paddock level increased within a given crown cover range (0 - 15 %) and then decreased above 20 %. This tendency was more evident during the dry season than in the wet season (Figure 1). The higher SHB availability obtained during the rainy season compared to the dry season is in response to the rainy pattern observed in the study zone. The higher regression value obtained during the dry season reflected the favored microclimatic conditions caused by the shelter benefits that trees provides for pasture growth when this is limited by the adverse climatic conditions during drought periods in the dry tropics. Although microenvironmental variables were not measured in this study, in Cañas, Costa Rica, average wind speed (35 km h^{-1}) during the dry season (January to April) is twice that in the rainy season (15 km h^{-1}) and temperatures are higher and this environmental conditions increases soil and pasture evaporation rates limiting its growth. Thus, reduced wind speed and lowered temperatures by trees reduces grass water stress favoring pasture production (Ludwing *et al.* 2001) and these may explain the higher levels of production found in paddocks with moderate crown cover. Several authors have reported that trees reduce wind speed, lowered soil and environmental temperatures and maintain higher levels of moisture near trees compared to open pasture pastures. (Belsky 1989; Wilson *et al.* 1990; Rohades and Sharrow 1990; Vandelbeldt and Williams 1992; Belsky *et al.* 1993a; Singh *et al.* 1998; Montard *et al.* 1999; Carvalho *et al.* 2002)

Our study also showed that there were only a few paddocks with high (> 20%) levels of tree crown cover. Additionally, there were large gaps between the low-medium (< 15%) and high (> 20%) tree crown covers (Annex 2) that may represent a weakness in the interpretation of the regression analysis make it unreliable. However, recent studies conducted in tropical dry ecosystems support our increased trend findings within a moderate crown cover range. Casasola *et al.* (2001) found that forage (kg DM ha^{-1}) in a dry ecosystem in Nicaragua was similar between paddocks with high tree density (>30 trees ha^{-1}) than those with lower tree density (<30 trees ha^{-1}). In another study conducted in Brazil, Alvin *et al*. (2004) found that the DM availability of *B. decumbens* increased from low (12%) to medium (22%) tree cover percentage and then decreased above tree cover levels of 30%. The DM increase was attributed to the improved soil chemical condition caused by trees as well as to favored microclimate produced by trees.

Tree species composition of paddocks of this study (data not shown) as well as results from the tree inventory in pastures in the same study area showed that there was heterogeneous distribution and a wide diversity of tree species scattered in pastures in different arrangements. This include isolated and small cluster of leguminous, non-leguminous and deciduous tree species with different crown shapes and sizes (Esquivel *et al*. 2003). This pattern of tree cover in pastures, compared to closed forest/fruit plantations, may result in more light penetration and less competition for resources between the associated crops favoring the action of positive interactions causing the increased trend in the amount of SHB observed within a given crown cover range (Figure 1). Positive interactions could include increased soil quality as a result of improved soil chemical composition (Sae-Lee *et al*. 1992; Rodriguez *et al*. 2000, Alvin *et al*. 2004), N fixation by leguminous trees (Durr and Rangel, 2001), higher organic matter accumulation through the litter fall of deciduous trees (Crespo and Fraga 2002; Alvin *et al*. 2004), higher N mineralization rates (Rhodes 1995) and faster litter breakdown favored by a shade (Humphereys 1994; Wilson 1996). Increased grass growth under mixed tree stand compared with grassland growing in and adjacent open areas has been reported for the semiarid regions of India (Saxena *et al*. 1996).

In contrary to the positive effects that moderate tree cover had on SHB, less light reaching the understorey and higher competition for nutrients and water between trees and grasses in paddocks with higher tree cover ranges (> 30%) as well as that growing directly under the canopies (shade) of the tree species selected reduced the SHB dry matter availability in comparison to SHB harvested from outside the canopy (open) in this study. Shading is thought to be responsible for reducing standing herbage biomass yields directly underneath tree canopies. Tree shade limits pasture photosynthesis (Rao *et al*. 1998; Montard *et al*. 1999; Sharrow 1999) particularly in C_4 species, such as *B. brizantha* which can not saturate their photosynthesis rates even at full radiation levels. However, the extent of biomass reduction largely depends on the interception of solar radiation caused particularly by the tree species. Laurel, roble and coyol tree species have small tree crown areas (19.5 to 90 m^2) and when they occur as individual trees they permit the transmission of higher PAR under their canopy in comparison to the other tree species such as guacimo and Guanacaste which have lower levels of light transmission (< 30%) which explains the differences found between tree species selected. Similar findings have been reported by Eriksen and Whitney (1981) who found that although the DM yield of six tropical pastures varied among pasture species, a general decreasing yield trend occurred as light intensities were artificially decreased with shade cloths from 100 to 27% full sunlight. Similarly lower grass yields have been measured under dense and large tree canopies such as *Mangifera indica*, *Prosopis juliflora*, *Adansonia digitata* when compared to lighter crowns like laurel, roble and *Acacia tortilis* (Frost and McDouglald 1989; Belsky *et al*. 1993a; Belsky *et al*. 1993b; Ribaski and Menezes 2000; Souza de Abreu *et al.* 2000).

Cattle grazing could be another factor that affected standing herbage biomass yields underneath trees. Although cattle were excluded from sampled paddocks during the sampling dates, cattle have been previously grazed in the selected paddocks. Hence, repeated defoliation of SHB under tree canopies due to a higher nutritive quality of the SHB under tree canopies may explain the lower SHB found directly under tree canopies in comparison to the open areas. It has been reported that grass under light environments allocates a higher proportion of carbohydrates to maintain or increase leaf area while reduces biomass allocation to roots (Kephart *et al*. 1992; Dias-Filho 2000). Thus, since forage re-growth depends to a large extent on mobilization of reserves stored in roots after defoliation, frequent defoliation caused by cattle reduces tillering rates which consequently decreases light interception by grass affecting persistency and productivity of forage growing under tree canopies (Gautier *et al*. 1999; Dias-Filho 2000).

Botanical composition

Presence of grass and broad leaved weeds will depend upon the growing rates of each species based on the conditions under the tree canopies. Grasses are characterized by rapid growth rates, relatively short life spans, large amounts of energy allocated to sexual reproduction and high photosynthetic rates requiring high levels of light and nutrients to grow in competition with broad-leaf herbaceous plants. Thus, the high abundance of broad-leaved weeds found in shade levels > 30% in paddocks as well as under individual tree species suggests that growth and production of *B. brizantha* was limited by these light conditions. These results concur with other authors which reported that shade levels > 35% under tree canopies or shade cloths reduced the presence of grasses and favored the establishment of the more shade-tolerant tree seedlings and broad leave weeds that are of low palatability and normally not eaten by cattle (Eriksen and Whitney 1981; Chen and Wong 1983; Chen and Othman 1984; Wong 1990; Otero-Arnaiz *et al.* 1999; Kaushal *et al.* 2000; Penton 2001). Additionally, the individual species showed that bare soil was more apparent underneath Guanacaste, guacimo and genizaro than under the canopies of tree species with smaller crown size and higher light penetration. These results, apart from the low light levels reaching their understorey, could have been caused by trampling and by the excessive dung and urine deposited by cattle resting under the shade of these preferred tree species (Stokes 2001; Muñoz *et al*. 2003).

Standing herbage quality

Standing herbage crude protein (CP) content increased significantly under all tree species compared to that observed in the open pasture. This is consistent with reports in the literature that found higher CP concentrations of forage under tree canopies compared to open pastures for a broad range of ecosystems (Belsky *et al*. 1989; Cruz 1997; Castro *et al*. 1999; Lin *et al*. 2001; Ludwig *et al*. 2001; Carvalho *et al.* 2002). The improvements in grass nutritional quality observed under shade in comparison to that at the open pastures can be due to higher N mineralization rates as well as to morphological and physiological changes that plants adopt when growing in shade. Reduced light is associated with greater allocation of assimilates for leaf tissue development than roots as a mechanism of adaptation under shade (Cruz 1997; Dias Filho 2000). Shading increases specific leaf area, increases shoot:root ratios and causes leaf elongation, diminishing the fiber content and increasing N content of grasses (Dias Filho 2000; Durr and Rangel 2002). Deinum *et al.* (1996) found that *B. brizantha* tillers growing at full sunlight were older and less nutritious than those growing in shade. High light and temperatures, such as occurs in the dry tropics, promote an increase in pasture growth rates hastening grass maturation which in consequence increases cell-wall contents (lignin and hemicelulose) lowering CP content of forages. Another mechanism that can explain higher CP of forage growing under trees is an increase in soil fertility caused by higher organic matter and nutrients through litter fall and N fixation. Nutrient recycling through litter fall has been considered a great contribution to increased soil fertility (Eckert and Coleman 1998; Crespo and Fraga 2002). Similarly, various studies have shown that soil samples under leguminous trees had higher N contents compared to soils outside the tree canopies (Vandelbeldt and Williams 1992; Belsky *et al.* 1993a; Durr and Rangel 2000; Ludwing *et al.* 2001; Durr and Rangel 2002). Higher CP in the standing herbage biomass under the canopy may also be associated with N recycling via urine and dung droppings by cattle under the trees (Hawke *et al.* 1999; Rodriguez *et al.* 2003) as well as by birds that utilize trees for shade and roosting sites (Belsky 1992; Gibbons and Boak 2002).

Dry matter digestibility depends upon chemical composition of the feedstuff, but mainly upon lignin content in the cell-wall. Broad leaf weeds contain higher stem proportions than grasses which in consequence represent higher content of the less digestible material. Thus, differences in the standing herbage biomass IVDMD found between tree species as well as between sampled zones could be attributed to differences in the botanical composition of SHB harvested underneath tree canopies. The botanical composition of SHB under the canopy of Guanacaste was dominated just by a single broad-leaf weed species, whereas that of guacimo consisted of large proportions of various low growing hard stemmed broad-leaf weeds in combination with grass. Under the other tree species, *B. brizantha* grass was the major cover under the canopy. These differences may explain the lower significant percentage of IVDMD of SHB under the canopy of Guanacaste and guacimo in comparison to the other tree species.

Fruit production and quality

It should be noted that fruit production measurements in this study were only carried out in one dry season and large fruit production variability occurred between individual trees within the same species. Although this could be a limiting factor in the use of fruits for long term planning of silvopastoral systems, this study showed that pastures containing a mixed assemblage of multipurpose tree species with different fruit phenologies and distribution pattern during the dry season should be incorporated into the design of silvopastoral systems to ensure a synchrony between fruit production with that of the reduction in standing herbage biomass of pasture plots. The species coyol and guacimo produced fruit at the beginning of the dry season whereas genizaro and Guanacaste produced higher fruits in the middle and the end of the dry season when standing herbage biomass is scarce and with low nutritional quality for the animals to meet their nutritional requirements. Thus, the inclusion of a mixture of tree species in pastures will provide cattle with additional fodder sources of higher nutritive quality that grasses providing a stable diet to cattle during the dry seasons. This allows cattle to select high quality feed and also obtain adequate fodder intake contributing to the maintenance of live weight during the dry season when most animals suffer live weight losses due to limitations of both, forage availability and nutritional quality.

Previous studies have shown that large variations occur between individual trees within the same species with respect to the amount of fruits produced (Janzen 1982b). These variations are related to specific site conditions as well as to individual tree physiological factors such as age, provenance, and production pattern (Janzen 1982b; Mora 1990; Durr 1992; Scariot and Lleras 1995). Although the large fruit variability found makes difficult to compare the fruit production from this study with other studies, the amount of fruits produced in this study are within the fruit production ranges reported for the tree species selected.

Fruits from the tree species studied have been proven to be an excellent source of available nutrients, particularly protein and energy, to cattle (Devendra 1995; Navas *et al.* 2001; Restrepo *et al.* 2004; Perez *et al.* 2005). Fruit inclusion in cattle diets has contributed to increased cattle productivity in farm systems based on pastures where the use of concentrates has been proven to be unprofitable (Rueda *et al.* 2003) and fruits may be the only low cost alternative of supplementation for the animals. A tree inventory data in the same study zone (Esquivel *et al.* 2003; Villanueva *et al.* 2003) showed that there were large percentages (27% of total individuals inventoried) of fruit bearing trees that are consumed by cattle and most paddocks had low tree cover (< 10%) with a mixed assemblage of tree species. Because SHB production is not affected by tree cover levels up to 20 %, this implies that farmers can increase the tree cover in pastures with fruit bearing tree species without experiencing sharp declines in SHB and obtain the combined fruit production to feed cattle during the dry season. However, local knowledge studies (Stokes 2001; Muñoz *et al.* 2003) showed that apart from the grass reduction caused by trees, farmers did not have a good understanding of the less tangible improvements in cattle production that could be obtained by maintaining and planting mixed assemblage of trees in pastures. Therefore participatory approaches should be used to facilitate farmers to identify the complementarities between trees and farms based on their production objectives (Augusseau *et al*. 2005). This in consequence, may help them to make decisions as to how to design better silvopastoral systems incorporating fruit producing trees.

Implications for management

The inventory results of tree resources in pastures in the study area showed that a large percentage of the pastures are composed mainly with timber tree species but with tree cover less than 10% (Esquivel *et al*. 2003; Villanueva *et al*. 2003). However, this study shows that a crown cover between 0- 20% had little effect on the standing herbage biomass of the pasture indicating that there are good opportunities for increasing tree cover without suffering losses in animal productivity. Higher tree cover resulted in decreased standing herbage biomass production but the quality of the pasture was improved.

During the rainy season there is an excess of forage produced by pasture and during the dry season there is a lack of forage supply. These pastures can not provide sufficient energy and protein to cover the requirements of cattle maintenance. Inadequate nutrition constrains cattle live weight gains and forces farmers to sell their animals at lower prices. However, multipurpose tree species produce fruits of higher nutritional value than grasses, especially in the middle and the end of the dry season when there is little forage available in the pastures. Therefore an increase in tree cover between the ranges of 20 to 25% including fruit bearing tree species may not have negative effects on live weight gains and milk yields of animals, but could provide additional energy and protein sources resulting in improved animal production. Many farmers eliminate trees in pastures because of the negative impacts on pasture production but apparently this decision do not consider the beneficial role that the large canopy fruit bearing tree species have to cattle during the dry season. This implies that farmers can make decisions on combining timber tree species with tree species that increase forage and fruits supply. This strategy will allow farmers to have constant supply of feed to cattle during the dry season and more stable production all year round. Increasing tree cover in pastures of traditional cattle farm systems with an assemblage of different tree species will not only improve cattle productivity but also increase land value thought fertility and less degraded land and farmers will obtain additional incomes apart from cattle (Rosales 1999; Sanchez 1999; Calle *et al*. 2001; Devendra and Ibrahim 2004).

Conclusion

The net effect of tree cover on fodder production is a function of both, tree species present and their densities that they occur. High crown cover (>20%) as well as tree species with dense and large crowns and low light transmission (< 30%) such as Guanacaste and guacimo reduce standing herbage biomass and increase the presence of broad leave weeds to a higher extent than moderate crown cover (< 20%) and tree species with lighter tree canopies such as laurel, roble and coyol. This suggests that these light conditions, apart from possible nutrient and water competition, are unfavorable for the growth of *B. brizantha* grass. *Brachiaria brizantha* paddocks in a tropical dry ecosystem covered with moderate crown cover (10 – 15%) composed by a mixed tree species assemblages with different fruit phenologies increases the nutritive quality of pastures and provides additional fodder to cattle representing an advantage for animal production since it increases the overall fodder nutritional value available to cattle. It can be concluded that *B. braizantha* grass support moderate crown cover including the multipurpose guacimo and genizaro tree species as well as laurel and roble timber tree species in such a way that the combined mixture of tree assemblage of pastures apart of provide additional farm incomes, provides a more stable overall fodder nutritional value available to cattle during the dry season than monoculture paddocks that may compensate for the declines in standing herbage biomass resulting in improved animal and farm production.

CHAPTER V

Modeling the impacts of tree cover dispersed in pastures on productivity and nutritive quality of fodder to cattle in silvopastoral systems in a dry ecosystem.

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Abstract

In Central America landscapes dominated by pastures and cattle contain a mixture of tree resources that serve as important ecological functions. However, there is limited information about the potential contribution that tree species mixture with different tree densities and crown types dispersed in pastures have on livestock productivity. Using computer simulations, we modeled the availability and nutritional quality (crude protein and metabolizable energy) of the total fodder (grass and fruits) to cattle and their live weight changes in a baseline scenario (BLS) consisting of a *Brachiaria brizantha* pasture in monoculture, as well as for five different silvopastoral (Light, Moderate, Dense, Mixed and Fruit) scenarios (SPS) varying tree species composition based on tree species canopy types. Each of the SPS was modeled at five different crown cover (CC) percentages (this is the paddock area that is directly underneath tree canopies) ranging from Low (10%) up to Very high (50%). The model was developed using Simile 4.2 and was run once for each scenario - CC combination (n = 26) and its outputs were used as inputs into the LIFE-SIM 3.2 model to simulate steers live weight changes over a one year period. Simulation showed that increasing CC in pastures from low (10 %) to very high (50 %) reduces availability of *B. brizantha* grass dry matter (kg DM ha^{-1}) from 2.7 up to 51.3% relative to that produced in BLS, but the effect of the CC depended on tree species composition. Higher grass DM yields reductions were observed in the dense SPS. Increasing tree cover contributes to higher fruit production but the contribution of fruits to total fodder dry matter depended on tree species composition in pastures being highest in the dense, mixed and fruit SPS. Moderate, mixed and fruit SPS simulated had 1.5 and 49.1% higher total fodder crude protein (kg CP ha^{-1}) whereas all SPS had lower total fodder metabolizable energy (Mcal ha^{-1}) compared with the BLS. Live weight gains in the SPS were higher (40 - 45 g day^{-1} $animal^{-1}$) compared to BLS. Simulations performed suggest that increasing CC of pasture plots to moderate (30%) percentages including fruit bearing tree species can improve cattle productivity by the provision of additional fodder of higher nutritional quality than pastures compensating the grass losses caused by trees.

Key words: *Brachiaria brizantha*, cattle, silvopastoral systems, simulation, tree species, live weight changes, crown cover, crude protein, metabolizable energy.

Introduction

In Central America landscapes dominated by pastures and cattle contain tree resources that serve important ecological functions (Velazco *et al*. 1998; Cardenas *et al*. 2000; Harvey *et al*. 2005; Chacon and Harvey 2006). The patterns of tree resources include live fences, isolated and or clusters of trees in pastures, secondary forest, charrales (areas under vegetal succession) and remnant forest (Restrepo *et al*. 2003; Esquivel *et al*. 2003; Villanueva *et al*. 2003; Sanchez *et al*. 2005). Studies conducted on cattle farm systems in the dry tropical areas of Central America showed that tree resources are affected by many factors including farm system, farm intensification level, tree structural characteristics (crown type, tree size), land use, paddock slope and size (Esquivel *et al*. 2003; Muñoz *et al*. 2003; Villanueva *et al*. 2003; Sanchez *et al*. 2005). Moreover, local knowledge studies in the same area showed that farmers have a wealth of knowledge of tree resources in pastures in terms of how trees affect pasture productivity and in terms of their importance to provide timber, firewood and feed and shelter to cattle (Stokes 1999; Muñoz *et al*. 2003). Many livestock farmers make decisions on the amount and type of tree species to retain in their pastures based on tree crown size and on the impact that trees have on pasture production. Farmers gave preference to tree species with small and less dense canopies like coyol laurel and roble which have little effect on pasture production. However, multipurpose trees provide other services on the farms including the production of fruits which is an important source of feed for cattle in the dry season (Navas and Restrepo 2001; Palma y Roman 2001; Zamora *et al* 2001).

Although farmers have wealth knowledge of the effects of trees on pasture productivity, they lack information about fruit production from a mixed cover of a varieity of tree species and how they can mitigate the effects of forage reduction under the canopy of these trees and improve cattle productivity. Traditional cattle production is generally based on grass monocultures and in seasonally dry areas there is an excess of grass production in the wet season and a deficit in the dry season. Thus, the lack of forage of high nutritional value during the dry season represents a major limitation for animal production in such a way that during this time animals usually loose weight (FAO 2000; Shelton 2004; McIvor 2006).

One way to overcome this problem is to diversify fodder production by integrating multipurpose trees in the pastures. Many studies in silvopastoral systems have focused on measuring annual productivity of pastures but there are few studies measuring the seasonality of forage and/or fodder production to better understand the role of trees in traditional silvopastoral systems. Esquivel *et al* (in press) measured production and quality of fruits from four multipurpose tree species that provide additional higher quality fodder to cattle during the dry seasons. The value of maintaining a variety of tree resources in mitigating heat stress and improving animal production was also studied (Souza de Abreu *et al*. 2000; Restrepo *et al*. 2000; Betancourt *et al*. 2003). While these studies provide insights to the use of mixtures of tree species in pastures in traditional silvopastoral systems, there are no reports on the impacts of these mixtures in pastures with different tree densities and crown types have on productivity of pastures, fruits and animals. In a well managed silvopastoral system the impact of tree cover on reduction of grass production may be of little significance since an excess of grass production occurs in the wet season when animals can satisfy their intake. On the other hand, in the dry seasons, the integration of fruit bearing tree species in pastures will add feed to cattle, thus improving animal performance. In order to determine mixtures of different tree species, we need to understand how different tree covers affect the supply of forage all year round and how trees might mitigate the effects of forage reduction. This paper reports reports the impacts of tree types and crown cover on pasture and animal productivity using simulation models. It explores the relationships between different tree mixtures and pasture productivity and what is the contribution of tree resources to nutrients in terms of crude protein and energy.

Methodology

Site description

The province of Guanacaste, Costa Rica is classified as tropical dry forest with elevations ranging from 60 to 250 masl (Holdrige 1978; Arauz 2001). The climate in the region is seasonal, with a well defined wet season lasting from May to November. On average, approximately 85% of the annual rainfall is confined to these months which makes livestock production seasonally dependant (Figure 1). Temperature in the area varies between 24 and 31º C during the year and relative humidity fluctuates between 62-89 and 52–77% in the wet and dry seasons respectively (Taboga Meteorological Station, 2003).

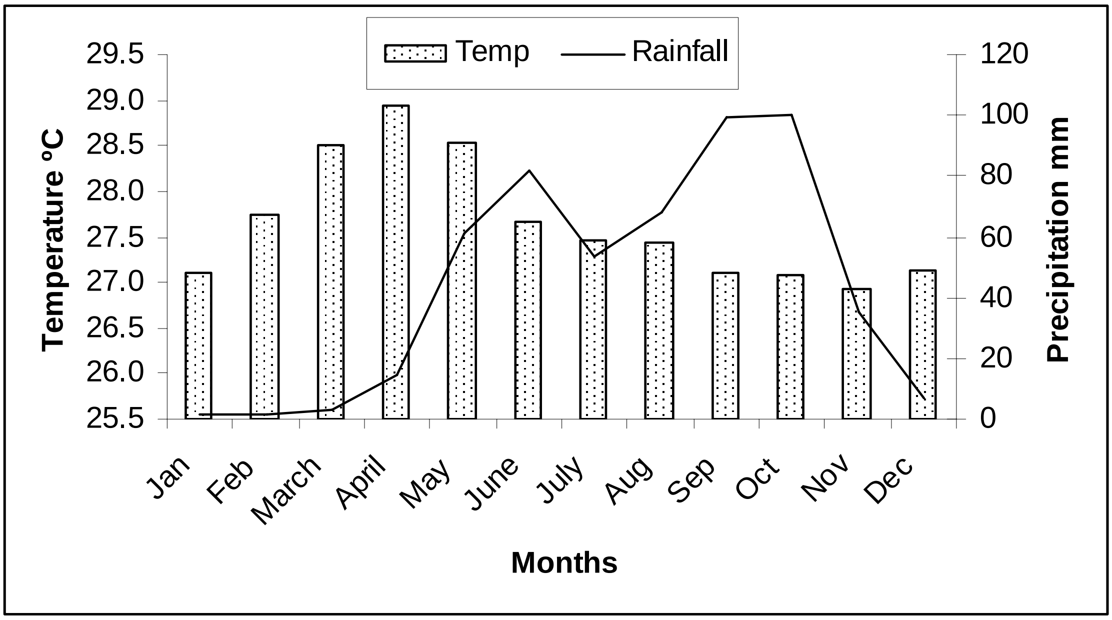

Figure 1. Mean monthly variation (1985 – 2003) in temperature and rainfall in the study area. Data obtained from Taboga meteorological station, Cañas, Guanacaste, Costa Rica, 2004.

The main farm production activity undertaken in the area is beef cattle ranching with Zebu cattle breeds. Most beef cattle farms in Cañas ranged from 18 to 241.3 ha in size with a mean of 67.0 ha (± 14.9). Farms had on average 12.5 (± 1.9) pasture plots per farm with a mean size of 4.2 ha (± 0.28) ranging from 0.1 up to 23.0 ha. Most cattle farms (70%) had pasture plots sown with *Brachiaria brizantha* with a mixed assemblage of naturaly regenerated dispersed tree species and bordered by live fences planted by farmers (Esquivel *et al*. 2003; Villanueva *et al,* 2003; Harvey *et al,* 2005). The main tree species present in the live fences were *Bursera simaruba* (indio desnudo) and *Pachira quinata* (pochote) whereas *Acrocomia aculeata* (coyol), *Andira inermis* (almendro), *Byrsonima crassifolia* (nance), *Cordia alliodora* (laurel), *Enterolobium cyclocarpum* (Guanacaste), *Guazuma ulmifolia* (guacimo), *Samanea saman* (genizaro), *Tabebuia ochracea* (cortez amarillo), and *Tabebuia rosea* (roble) were the main tree species dispersed either isolated or forming small clusters in pastures. Mean richness, density and crown cover (defined as the percent of the pasture area that was directly under tree crowns) of dispersed trees in pastures in the study area was 2.8 (± 0.22) tree species ha^{-1}, 8.1 (± 0.66) trees ha^{-1} and 6.9 % (± 0.54) respectively. Tree richness varied from 0 to 21.2 tree species ha^{-1}, tree density ranged from 0 to 68 trees ha^{-1} and crown cover ranged up to 49 percent (Esquivel *et al.* 2003).

Model construction

A tree inventory conducted in 196 paddocks (836 ha) in 16 cattle farms in the seasonally dry areas of Cañas, Guanacaste, Costa Rica evaluated the pattern of tree cover in pastures (Esquivel *et al*. 2003; Chapter III). This study showed that dispersed trees in pastures were arranged almost equally between isolated individual trees (54 %) and trees in clusters (46 %). Moreover, the study showed that a large variation of tree species, individuals and tree sizes forming clusters occurred, whereas the multipurpose tree species *Acrocomia aculeata* (coyol), *Guazuma ulmifolia* (guacimo), and the timber tree species *Cordia alliodora* (laurel) and *Tabebuia rosea* (roble) were the most common and abundant mature individual tree species dispersed in pasture plots of cattle farming systems. These tree species represented 10.7, 12.6, 12.0 and 12.8 % respectively in relation to the total trees inventoried (n = 5,896). Additionally, local knowledge studies (Stokes, 2001; Muñoz *et al.* 2003) and informal farmers interviews in the same study area showed that apart from the most abundant tree species previously mentioned, *Enterolobium cyclocarpum* (Guanacaste) and *Samanea saman* (genizaro) were the most preferred tree species that produce shade and fruits to feed cattle during the dry seasons. A second study measured the impacts of isolated mature dispersed individual trees in production and quality of the grass available underneath their canopies and on the amount of fruits/pods, referred from now on for the purpose of this paper as “fruits”, produced by fruit bearing tree species (Esquivel *et al*. 2003; Chapter IV) but no information about the cluster effect was available. Thus, the combined information of these two studies as well as local farmers knowledge (Stokes 2001; Muñoz *et al.* 2003) and informal farmer interviews about tree species preference in the same study area, served to construct a simulation model to estimate the fodder (grass and fruits) dry matter (kg DM ha^{-1}), crude protein (kg ha^{-1}) and metabolizable energy (Mcal ha^{-1}) available to cattle as a function of varying tree specie composition and crown cover percent (the paddock area that is directly underneath tree canopies) of pasture plots. However, due to the fact that there was a large tree species variation found in clusters as well as that no information about cluster effects on pasture and fruits productivity was availble, the model only include isolated mature individuals from coyol, guacimo, laurel, roble, genizaro and Guanacaste tree species.

Model description

The model was constructed using the Simile 4.2 software program (Simulistics 2004) and runs on a monthly time step over one year period. It represents a one hectare size pasture plot containing *Brachiaria brizantha*, the most common improved grass specie in the study zone (Esquivel *et al*. 2003; Restrepo *et al*. 2003; Villanueva *et al*. 2003) and, hence included in the model, with or without individual mature trees species randomly dispersed within the pasture plot (Figure 2).

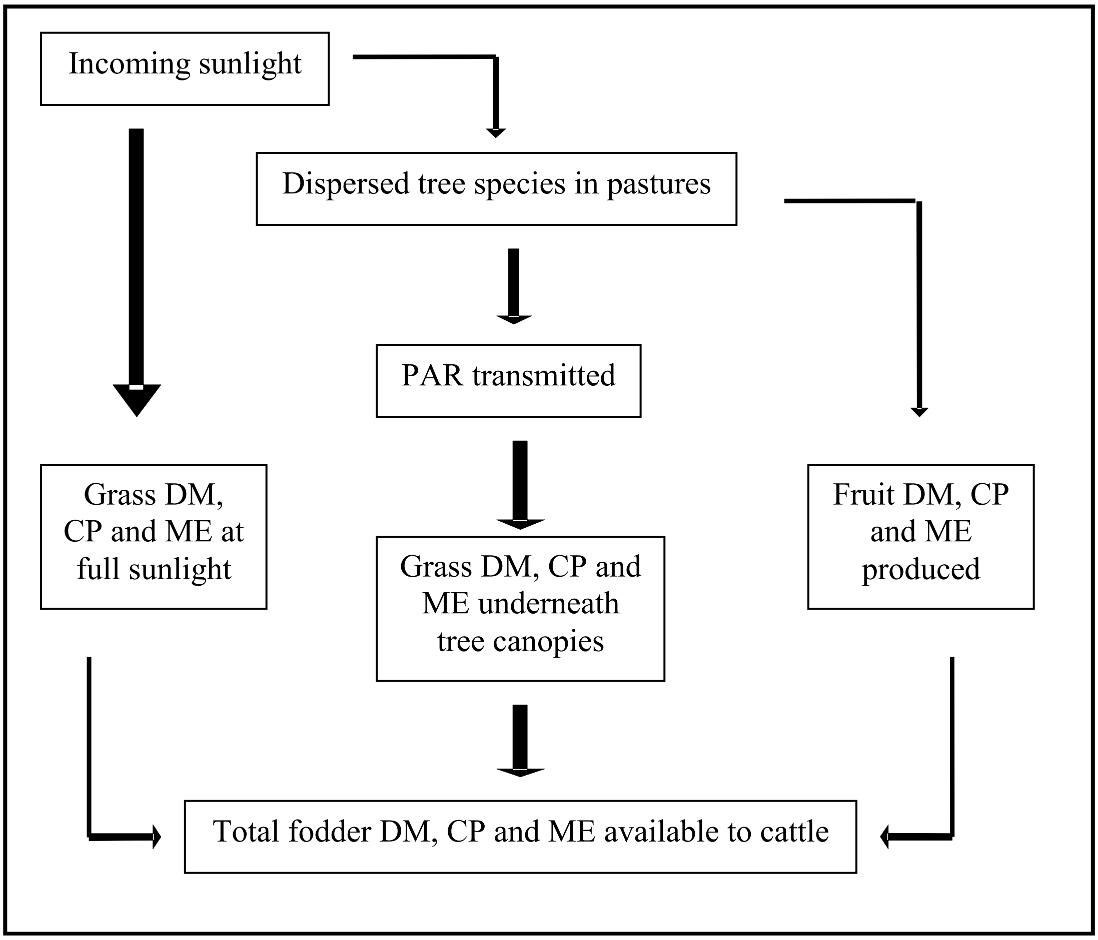

Figure 2. Schematic representation of a *Brachiaria brizantha* pasture plot showing the processes (arrows) considered in the model. PAR = Photosynthetical active radiation; DM = dry matter; CP = crude protein; ME = metabolizable energy.

Model parameters

Grass

Monthly *Brachiaria brizantha* grass (kg DM ha^{-1}) and their nutritional composition (CP and ME) available at open areas used in the model was obtained from research conducted by Ibrahim (unpublished data) in the tropical dry areas of Guanacaste, Costa Rica.(Table 1).

Table 1. Monthly *Brachiaria brizantha* grass dry matter (kg ha^{-1}), crude protein (g kg^{-1} DM) and metabolically energy (McCall kg^{-1} DM) parameters available at open areas (areas that receive full sunlight and are not affected by the root and crown influence of any tree) in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica used in the model.

Month	Dry matter (kg ha^{-1})	Crude protein (g kg^{-1} DM)	*In vitro* dry matter digestibility (%)	Metabolizable energy (Mcal kg^{-1} DM)
January	558	6.0	59	2.12
February	480	5.2	58	2.10
March	410	4.5	57	2.05
April	465	4.5	56	2.02
May	1000	6.5	57	2.05
June	1575	7.0	59	2.12
July	1612	8.0	61	2.20
August	1860	8.0	61	2.20
September	1750	9.0	63	2.30
October	1473	9.0	63	2.30
November	1670	8.0	62	2.23
December	1480	7.0	61	2.20

grass metabolizable energy (Mcal kg^{-1} DM) were obtained by multiplying the *in vitro* dry matter digestibility with the gross energy (4.4 Mcal kg^{-1} DM) and the constant of conversion of ingested digestible energy into metabolizable energy (0.82) with the following equation: ME = IVDMD * 4.4 * 0.82

Trees

Data from individual mature tree species dispersed in pastures from Esquivel (Chapter IV) showed that the availability of *B. brizantha* underneath tree canopies was reduced whereas CP was increased compared to that at open areas but the reduced and increased extent is largely influenced by the tree species. As a consequence, in the simulation model grass DM available underneath tree canopies was reduced whereas the CP was increased compared to that produced at open areas considering differences among tree species (Table 2). The same study shows that the effect of tree canopies upon the grass *in vitro* DMD underneath tree canopies was less consistent. Therefore it was decided to use the same IVDMD for both the grass available at open areas as well as that underneath tree canopy areas. Structural characteristics and canopy shade effects of the selected tree species (Table 2) were obtained from Esquivel (Chapter IV) and were considered as constant in the model due to the relative slow growth rates of mature trees in a year.

Table 2. Main tree characteristics of isolated mature individual tree species[§] dispersed in *Brachiaria brizantha* pasture plots (n = 836 ha) of 16 beef cattle farms in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica and used in the model (adapted from Esquivel 2006; chapter III).

	Tree species					
Characteristics	Coyol	Genizaro	Guacimo	Guanacaste	Laurel	Roble
Crown size (m^2 $tree^{-1}$)	21.1	295.7	141.6	481.7	89	61.7
dbh (cm)	36.4	57.3	58.9	92.6	42.8	36.5
PAR transmitted (%)	60.6	49.4	33.7	27.1	64.4	54.9
Grass reduction (%)[@]	12	30	62	77	27	22
Weed presence (%)[&]	5	44	90	100	2	2
Grass CP increased (%)[$]	25	67	40	128	24	28
Tree crown type[#]	light	moderate	dense	dense	light	moderate
Main use	fruits	fruits, timber	fruits	fruits, timber	timber	timber

[§] Out of total individual trees (n = 2,838) from the six tree species used in the model; Crown size = calculated from the elliptical crown area based on the two longest crown diameter measures; dbh = diameter at breast height; PAR = photosynthetic active radiation measured underneath tree canopy and expressed as a percentage of full sunlight; [@] Grass reduction percent underneath tree canopies relative to that produced at open areas (full sunlight); [$] Grass crude protein increment percent underneath tree canopies relative to that at open areas (full sunlight); [&] weed percent presence underneath tree canopies; # = Estimated from the PAR % data.

Fruits

Monthly fruit production (kg DM $tree^{-1}$) and their nutritional quality (CP, IVDMD and ME) of each of the tree species producing fruits (coyol, genizaro, guacimo and Guanacaste) used in the model (Table 3) were obtained from fruits samples collected by Esquivel (Chapter IV) in tropical dry cattle farms of Guanacaste, Costa Rica. Monthly fruit production and their nutritional composition for each individual from the same tree species were considered constant into the model.

Table 3. Fruits[w] dry matter production (kg DM tree^{-1}), crude protein (g kg^{-1} DM), *In vitro* dry matter digestibility (%) and metabolizable energy (Mcal kg^{-1} DM) of the tree species used in the model.

	Tree species			
	Coyol	Genizaro	Guacimo	Guanacaste
	Dry matter (kg tree^{-1})			
January	1.5	0	0	0
February	2.0	0	13.3	0
March	1.0	17.2	8.0	5.6
April	2.2	12.5	0.1	56.0
May	0.5	0.2	0	12.8
Total	**7.2**	**29.9**	**21.4**	**74.4**
	Crude protein (%)			
January	5.7	na	na	na
February	5.5	na	6.6	na
March	6.1	15.7	7.4	14.7
April	5.1	15.5	8.2	12.3
May	4.8	na	na	12.2
Mean	**5.4**	**15.6**	**7.4**	**13.0**
	In vitro dry matter digestibility (%)			
January	68.7	na	na	na
February	66.9	na	69.2	na
March	64.0	71.6	62.8	70.1
April	67.9	70.4	60.1	66.9
May	67.6	na	na	66.3
Mean	**66.4**	**71.1**	**63.3**	**67.8**
	Metabolizable energy (Mcal kg^{-1} DM)			
January	2.5	na	na	na
February	2.4	na	2.5	na
March	2.3	2.6	2.3	2.5
April	2.5	2.5	2.2	2.4
May	2.4	na	na	2.4
Mean	**2.4**	**2.6**	**2.3**	**2.4**

w = mean of 7 individual trees of each tree species obtained from Esquivel 2006 study; na = not applicable; DM = fruit dry matter; CP = fruit crude protein; IVDMD = *In vitro* dry matter digestibility; Fruit metabolizable energy (Mcal kg^{-1} DM) calculated with the gross energy (4.4 Mcal kg^{-1} DM) and the constant of conversion of ingested digestible energy into metabolizable energy (0.82) with the following equation: ME = IVDMD * 4.4 * 0.82

Model development

The model requires that the "desired" number of mature (fixed crown size) individuals of each of the tree species (inputs) for each scenario is set before running the model. Based on this, the model calculates crown cover, considering tree crown size of each species (Table 1) and the number of individuals of each tree species set to separate it from the open areas. Crown cover (CC) in the model is calculated as the sum of crown sizes from all dispersed trees in pastures by the following formula:

$$CC = \frac{\sum_{i=1}^{n} N_i * CS_i}{10000}$$

Where:

CC = tree cover (ha)

N_i = number of individuals for tree species i

CS_i = crown size for tree species i (m^2 tree)

The model then calculates the total grass dry matter (TGDM; kg DM ha^{-1} $month^{-1}$) produced within the pasture plot which is the summation of grass produced in open areas (areas receiving full sunlight and without the root and crown influence of any tree) and that area under tree canopies (taking into account different reductions in grass production under different tree species). This is calculated in the model in the following way:

$$TGDM = GDMfs + GDMsh$$

Where:

GDMfs = grass dry matter at full sunlight areas (kg ha^{-1})

GDMsh = grass dry matter at shade (kg ha^{-1})

Grass DM production at full sunlight areas is calculated by the equation:

$$GDMfs = GDM * (1 - CC)$$

Where:

GDMfs = grass dry matter at full sunlight areas (kg ha^{-1})

GDM = grass dry matter production database (kg ha^{-1})

1 = total pasture plot area (ha)

CC = crown cover (ha)

For the grass dry matter produced underneath tree crowns, the model takes into consideration the pasture area that is covered by tree crowns and calculates the *B. brizantha* grass ratio lost under each one of tree crown specie compared to that produced at full sunlight. Thus, the model calculates the grass dry matter production underneath tree crowns of each of six tree species in the following way:

$$GDMsh = GDM * \sum_{i=1}^{n} N_i * CS_i * SE_i$$

Where:

GDMsh = grass dry matter at shade (kg ha^{-1})

GDM = grass dry matter (kg DM ha^{-1})

N_i = number of individuals for tree species i

CS_i = crown size for tree species i (m^2 tree)

SE_i = ratio underneath crowns related to full sunlight for tree species i

In the same sense, grass crude protein at the pasture level is the result of the crude protein available in the grass produced at full sunlight areas and that produced underneath tree cover which in the model is expressed as:

$$TGCP = GCPfs + GCPsh$$

Where:

TGCP = total grass crude protein (kg ha^{-1})

GCPfs = grass crude protein produced in areas of full sunlight (kg ha^{-1})

GCPsh = grass crude protein underneath each individual tree (kg ha^{-1})

GCPfs is calculated as follow:

$$GCPfs = GDMfs * GCP_{open}$$

Where:

GDMfs = grass dry matter production at full sunlight areas (kg ha^{-1})

GCP_{open} = grass crude protein content at full sunlight areas (g kg ha^{-1})

GCPsh is calculated as follow:

$$GCPsh = GDM * \sum_{i=1}^{n} N_i * CS_i * SE_i * GCP_{shadei}$$

Where:

GCPsh = grass crude protein under tree cover (kg ha^{-1})

N_i = number of individuals for tree species i

CS_i = crown size for tree species i (m^2 tree)

SE_i = ratio underneath crowns related to full sunlight areas for tree species i

GCP_{shadei} = grass crude protein concentration underneath tree crowns for species i (g kg DM ha^{-1})

Total fruit dry matter (TFtP) production (kg DM ha^{-1} $month^{-1}$) of fruit bearing tree species is calculated by adding up the individual fruit production of each of the six different tree species contained within the pasture plot. In the model this is calculated by:

$$TFP = \sum_{i=1}^{n} N_i * FP_i$$

Where:

TFP = total fruits production at the pasture plot (kg ha^{-1})

N_i = number of individuals for tree species i

FP_i = fruits production for tree species i (kg $tree^{-1}$)

Total CP (kg ha^{-1} $month^{-1}$) and ME (Mcal ha^{-1} $month^{-1}$) from fruits produced in the pasture plot is the result of multiplying the fruit production of each tree species by the CP and ME of the fruits of the same tree specie which are given by the following equations:

Total fruit crude protein (kg ha^{-1})

$$TFCP = \sum_{i=1}^{n} N_i * FP_i * FCP_i$$

Where:

TFCP = total fruits crude protein (kg ha^{-1})

N_i = number of individuals for tree species i

FP_i = fruits production for tree species i (kg $tree^{-1}$)

FCP_i = fruit crude protein for tree species i

Total fruit metabolizable energy:

$$TFME = \sum_{i=1}^{n} N_i * FP_i \ * FME_i$$

Where:

TFME = total fruit metabolizable energy (Mcal)

N_i = number of individuals for tree species i

FP_i = fruits production for tree species i (kg $tree^{-1}$)

FME_i = fruit metabolizable energy for tree species i

With all these calculations, the model adds up the fruit and grass dry matter production and its nutritional quality to calculate total fodder DM (kg DM ha^{-1} $month^{-1}$), total fodder crude protein (kg CP ha^{-1} $month^{-1}$) and total fodder metabolizable energy (Mcal ME ha^{-1} $month^{-1}$) produced within the pasture plot as a main model outputs.

Total fodder dry matter is calculated in the following way:

$$TFDM \ = TGDM \ + TFDM$$

Where:

TFDM = total fodder production (kg DM ha^{-1})

TGDM = total grass produced at pasture plot (kg DM ha^{-1})

TFDM = total fruits production at pasture plot (kg DM ha^{-1})

Similarly, total fodder crude protein is represented in the model as:

$$TFCP = TGCP + TFCP$$

Where:

TFCP = total crude protein production at pasture plot (kg ha^{-1})

TGCP = total grass crude protein at pasture plot (kg ha^{-1})

TFCP = total fruits crude protein at pasture plot (kg ha^{-1})

Total metabolizable energy in the model is calculated as:

$$TFME = TGME + TFME$$

Where:

TFME = total fodder metabolizable energy production (Mcal ha^{-1})

TGME = total grass metabolizable energy at pasture plot (Mcal ha^{-1})

TFME = total fruits metabolizable energy at pasture plot (Mcal ha^{-1})

Simulations performed

The constructed model was applied to simulate total fodder (grass and fruits) dry matter (kg DM ha^{-1}), crude protein (kg ha^{-1}) and metabolizable energy (Mcal ha^{-1}) available to cattle in an open scenario consisting of a *B. brizantha* pasture plot without tree cover, referred from now on for the purpose of this paper as the Baseline scenario (BLS), and in five different silvopastoral scenarios varying tree species composition based on tree species canopy type previously described. Silvopastoral scenarios were i) **Light** (LSS) which includes tree species with light crown type only (coyol and laurel), ii) **Moderate** (MSS) including moderate (genizaro and roble) crown type tree species only, iii) **Dense** (DSS) including dense (guacimo and Guanacaste) crown type tree species only, iv) **Mixed** (XSS) composed with a mixed assemblage of tree species of all crown cover types and v) **Fruit** silvopastoral scenario (FSS) consisting of a pasture plot composed only with fruit bearing tree species (coyol, genizaro, guacimo and Guanacaste) regardless of its tree crown cover type. Each of these scenarios, except the baseline, was modeled at five different tree crown cover percentages; **Low** (10%), **Intermediate** (20%), **Medium** (30%), **High** (40%) and **Very high** (50%). Tree crown cover percentages were chosen to cover the entire tree crown cover ranges (0 - 49%) found in pastures plots (n = 196) at beef cattle farms in Guanacaste region (Esquivel *et al*. 2003).

Tree density

The number of trees of each tree species included within the pasture plot simulated (Table 4) was based on the tree species that farmers prefer (farmers personal comm.) and tree species abundances order observed in pastures of cattle farm systems the area (Esquivel *et al*. 2006) in such a way that the sum of all individuals crown size (Table 2) from all tree species resulted in the tree crown cover percentage to be modeled.

Table 4. Number of mature isolated individual trees of each tree species included in *Brachiaria brizantha* pasture plots in the different simulations (n = 26) performed in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2006.

	Tree species						Density	Tree cover	
	coyol	genizaro	guacimo	Guanacaste	Laurel	roble	(n ha^{-1})	(m^2 ha^{-1})	(%)
Crown size	21.1	295.7	141.6	481.7	89	61.7			
Baseline	0	0	0	0	0	0	0	0	0.0
			Low tree cover (10%)						
Light	6	0	0	0	10	0	16	1016.6	10.2
Moderate	0	2	0	0	0	7	9	1023.3	10.2
Dense	0	0	4	1	0	0	5	1048.1	10.5
Mixed	1	1	1	1	1	1	6	1020.6	10.2
Fruits	4	1	1	1	0	0	7	1060.6	10.0
			Intermediate tree cover (20%)						
Light	12	0	0	0	20	0	32	2033.2	20.3
Moderate	0	4	0	0	0	14	18	2046.6	20.5
Dense	0	0	8	2	0	0	10	2096.2	21.0
Mixed	2	2	2	2	2	2	12	2041.2	20.4
Fruits	8	2	2	2	0	0	14	2006.8	20.1
			Medium tree cover (30%)						
Light	18	0	0	0	30	0	48	3049.8	30.5
Moderate	0	6	0	0	0	21	27	3069.9	30.7
Dense	0	0	12	3	0	0	15	3144.3	31.4
Mixed	3	3	3	3	3	3	18	3061.8	30.6
Fruits	12	3	3	3	0	0	21	3010.2	30.1
			High tree cover (40%)						
Light	24	0	0	0	40	0	64	4066.4	40.7
Moderate	0	8	0	0	0	28	36	4093.2	40.9
Dense	0	0	16	4	0	0	20	4192.4	41.9
Mixed	4	4	4	4	4	4	24	4452.6	44.5
Fruits	16	4	4	4	0	0	28	4013.6	40.1
			Very high tree cover (50%)						
Light	30	0	0	0	50	0	80	5083.0	50.8
Moderate	0	10	0	0	0	35	45	5116.5	51.2
Dense	0	0	20	5	0	0	25	5240.5	52.4
Mixed	5	5	5	5	5	5	30	5103.0	51.0
Fruits	20	5	5	5	0	0	35	5017.0	50.2

The model was run once for each scenario - crown cover combination (n = 26) and its outputs (fodder dry matter availability and their nutritive composition) were used as inputs into the LIFE-SIM 3.2 simulation software program (2004) to simulate Zebu steers live weight changes for one year period. Average daily live weight gains (DLWG) by Zebu steers in each scenario crown cover combination was calculated by dividing total weight gain by 365 days growing period. LIFE-SIM 3.2 program was used because it allows for the evaluation of different feeding strategies (scenario) on animal live weight performance considering the forage seasonal distribution, the additional supplemented feed given to cattle and their nutritional characteristics. Detailed description of the model can be found in Leon-Velarde *et al*. 2006 and inputs parameters and uinits used into Life-sim simulation model are presented in Table 5.

Life-Sim model main assumptions

To run the LIFE-SIM 3.2 model, the program requires to set the initial steer live weight, the stocking rate (number of animals per hectare) and the potential feed intake by steers (as percent of the body weight). Based on data from the same study zone (Villanueva, personal comm.) pasture plot stocking rate was set to 1.5 steer ha^{-1}, steers initial live weight was set to 200 kg and maximum dry matter intake per $animal^{-1}$ day^{-1} was estimated to be 3% of body live weight. Fruits into the LIFE-SIM 3.2 model are considered and entered as supplements and such that, the model requires to specify the supplement amount (kg fruit fresh $animal^{-1}$ day^{-1}) to be fed. Thus, based on studies conducted by Ku (unpublished data) in the semi-humid tropical areas of Yucatán, a maximum of 30% of the total diet provided by fruits was considered optimal to feed steers. With this information entered into the model, LIFE-SIM 3.2 assumes that steers eat all supplemented feed first and then considers the grass available to fulfill steers nutritional dry matter intake.

Table 5. Inputs parameters and unit used into life-sim simulation model.

Description	Units
Pasture availability	Kg DM $ha^{-1}month^{-1}$
Pasture digestibility	% DM
Pasture crude protein	% DM
Supplement (Fruit) offered	Kg fresh fruit $animal^{-1}day^{-1}$
Supplement (Fruit) dry matter	% DM
Supplement (Fruit) metabolizable energy	Mcal ME kg^{-1} DM
Supplement (Fruit) crude protein	% DM
Supplement (Fruit) digestibility	% DM

Results

Fodder availability

Grass

Simulated cumulated annual *Brachiaria brizantha* grass dry matter available to cattle was highest (14.3 t ha^{-1}) at the baseline scenario (pasture plots without tree cover) and declined as percent crown cover increases in all silvopastoral scenarios simulated. The highest DM reductions were observed in the pasture plots covered with dense crown type trees (dense scenario) whereas the lowest reductions were observed in the light tree crown scenario (Figure 3).

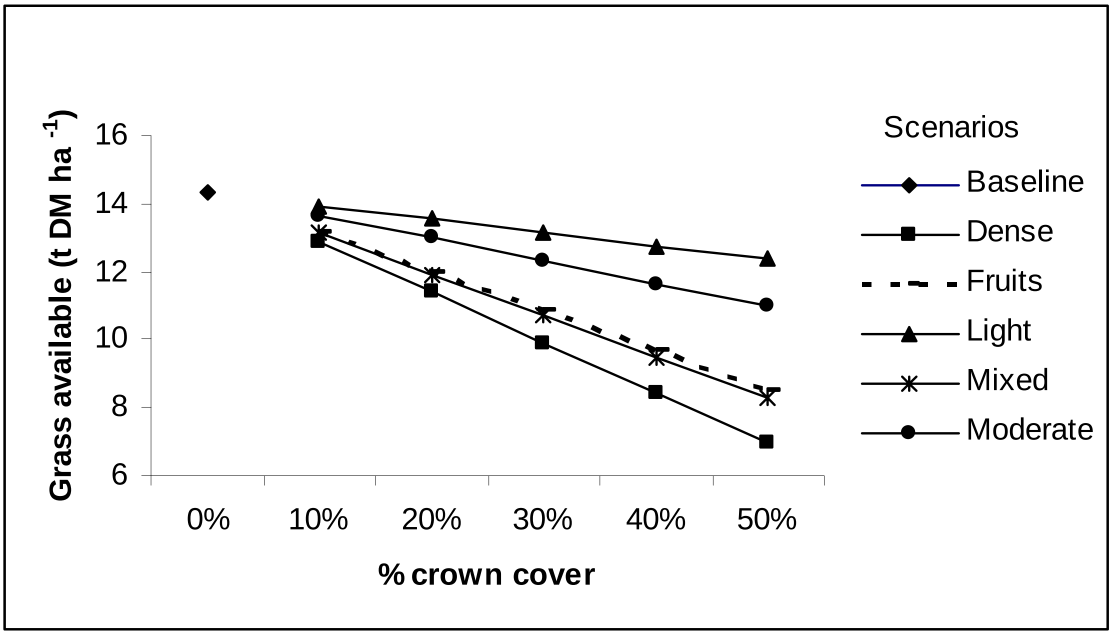

Figure 3. Annual *Brachiaria brizantha* grass dry matter available to cattle (t DM ha^{-1}) in the different scenarios simulated in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2006.

Cumulated annual grass DM availability decreased by 2.7% to 13.7% for light, by 4.7% to 23.4% for moderate and by 10.3% to 51.3% for dense canopy type scenarios as crown cover increases from 10 to 50% compared to baseline scenario. In the same way, simulation of pasture plots covered with fruit bearing tree species (fruit scenario) annual grass DM decreased by 8.1% to 40.6% as tree cover increases from 10% to 50%, which was found to be similar (8.4% to 42.1%) to that in the mixed tree scenario. Small differences (2.7 – 10.3%) in grass DM availability at all scenarios at the 10 % crown cover with respect to the baseline scenario became evident (13.7 – 51.3%) by the 50% crown cover particularly at the dense(51.3%), mixed (42.1%) and fruit (40.6%) canopy scenarios simulated (Table 6).

Table 6. Simulated annual *Brachiaria brizantha* grass dry matter available to cattle (t ha^{-1}) in the different silvopastoral scenarios in comparison to that produced (14.3 t ha^{-1}) in the baseline scenario (pastures without tree cover) in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2006.

	Tree crown cover (%)				
Silvopastoral Scenarios	10	20	30	40	50
Light	13.9	13.5	13.2	12.8	12.4
Moderate	13.7	13.0	12.3	11.6	11.0
Dense	12.9	11.4	9.9	8.4	7.0
Mixed#	13.1	11.9	10.7	9.5	8.3
Fruits&	13.2	12.0	10.8	9.7	8.5

Mixed silvopastoral scenario includes all tree species regardless its tree crown type
& Fruit silvopastoral scenario includes just fruit bearing tree species.

Fruits

Increasing the crown cover percentages in pastures resulted in higher cumulated fruit production (kg DM ha^{-1} year^{-1}) that was available to cattle with differences between scenarios due to differences in tree species composition. Fruit available to cattle was lowest in the light tree scenario and highest for the simulated dense tree scenario (Figure 4).

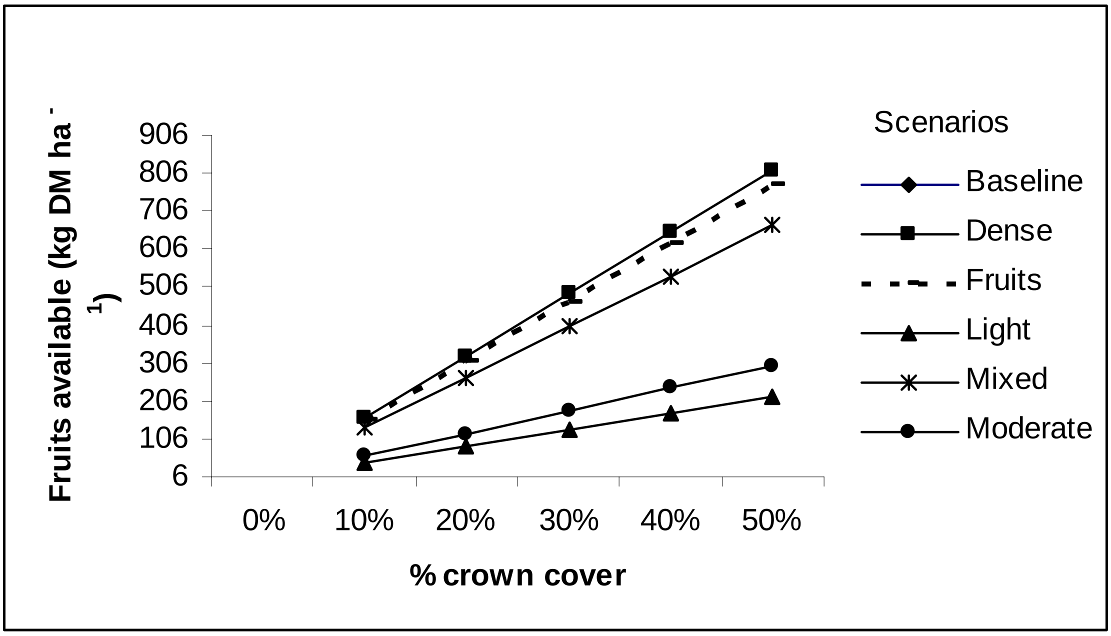

Figure 4. Cumulated annual fruits dry matter (kg ha^{-1}) available to cattle from dispersed trees in pastures during the fruit production period (January – May) in the different scenarios simulated in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2006.

Overall fodder biomass

Cumulated fodder (grass and fruits) biomass available to cattle during the fruit production period (January to May) was always higher at the baseline scenario (2913 kg DM ha^{-1}) compared to all other scenarios simulated and decreased as crown cover percent increased regardless of the tree canopy type scenario (Figure 5). The smallest (37 kg DM ha^{-1}) and the highest (681 kg DM ha^{-1}) fodder biomass differences with respect to the baseline scenario occurred for the low (10%) light scenario and the very high (50%) dense scenario respectively. Fruit production represented between 1.5% and 36.5% of total fodder biomass available to cattle depending on the tree specie composition. The light canopy scenario contributed to the total fodder biomass with the smallest percentages (1.5-7.9%) whereas the dense scenario contributed with the highest percentages (5.9 to 36.5%) as tree crown cover increased.

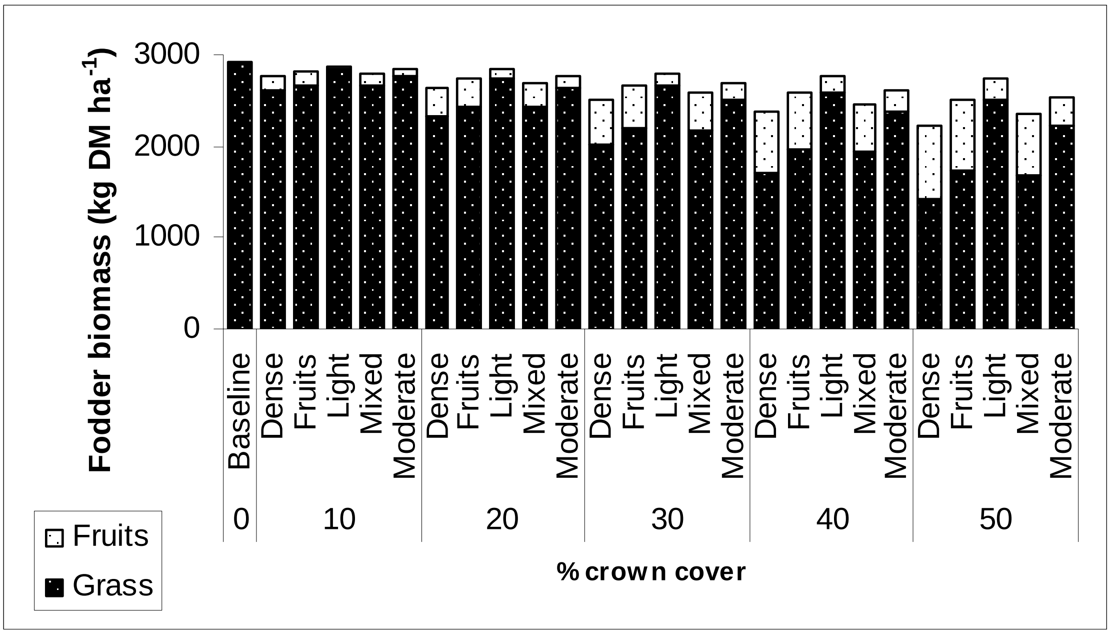

Figure 5. Cumulated fodder (grass and fruits) dry matter (kg DM ha^{-1}) available to cattle during the fruit production period (January to May) in the different scenarios simulated in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica 2006.

Fodder quality

Crude protein

The amount of cumulative crude protein in the baseline scenario was 162.8 kg ha^{-1} and it varied in the different silvopastoral scenarios depending on crown cover percentage and tree species composition (Figure 6). At the low crown cover percent (10%) cumulated fodder CP increased by 1.8, 2.1 and 2.8% in the mixed, moderate and fruit silvopastoral scenarios respectively whereas it decrease by 0.7 and 1.1 in the dense and light silvopastoral scenarios respectively in comparison with the baseline scenario. Fruits from silvopastoral scenarios produced between 1.5 and 49.1% of crude protein. The higher contribution was observed in the dense, fruit and mixed silvopastoral scenarios. Cumulated fodder crude protein differences between silvopastoral scenarios and the baseline scenario became greater as crown cover increased (Figure 6).

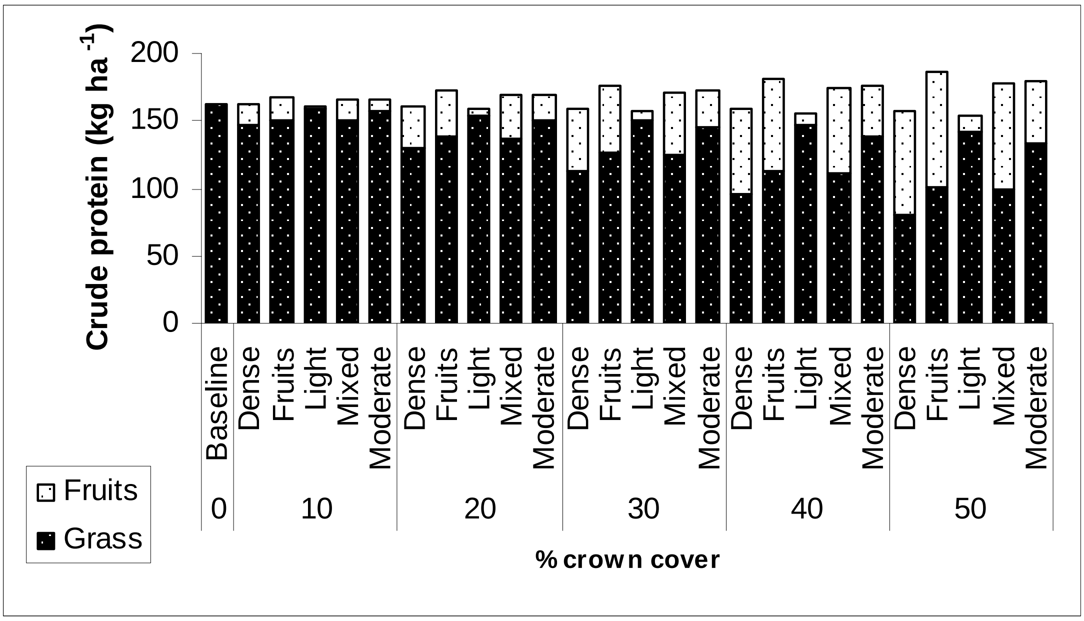

Figure 6. Cumulated amount of crude protein (kg ha^{-1}) during the period of fruit production (January-May) in the different scenarios simulated in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2006.

Metabolizable energy

Cumulated amount of metabolizable energy available to cattle was highest (6031 Mcal ha^{-1}) in the baseline scenario and it decreased in all silvopastoral scenarios as crown cover percentage increased especially with high tree cover. The greater reductions (4-20%) were observed in the dense scenario followed by the mixed (3.4-17.0%), moderate (3.0-15.1%), light (2.3-11.5%) and fruits (2.1-10.7%) scenarios respectively. However, fruit produced between 1.8 and 39.7% of total metabolizable energy available to cattle were the higher contribution was observed in the dense, fruit and mixed silvopastoral scenarios (Figure 7).

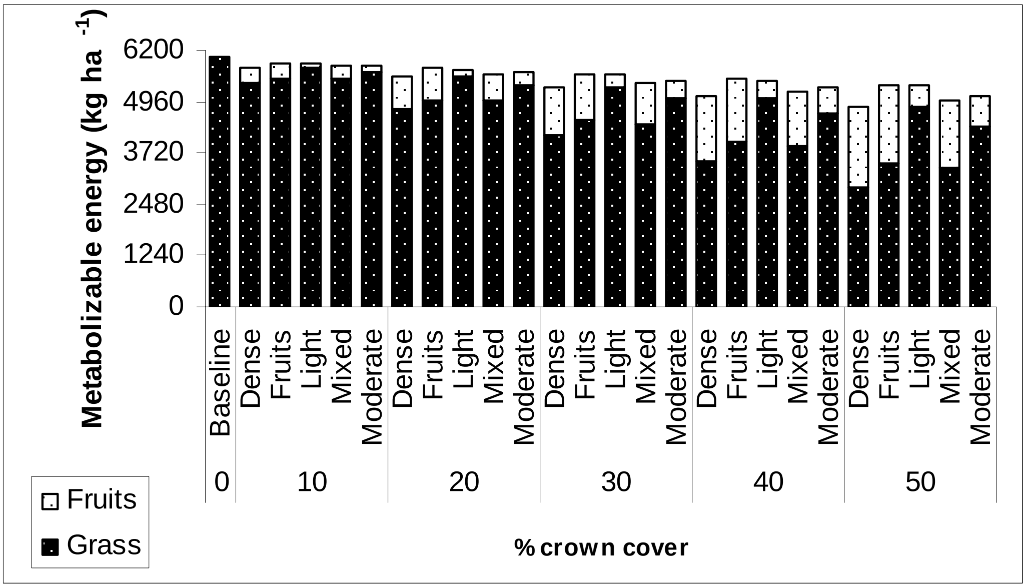

Figure 7. Cumulated amount of metabolizable energy (Mcal ha^{-1}) available during the period of fruit production (January–May) in the different scenarios simulated in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2006.

Animal performance

The simulated average daily live weight gain (DLWG) of zebu steers in the BLS was 350 g day^{-1} (average of 365 days). For the low (10%) crown cover, the simulated DLWG in the silvopastoral scenarios was between 40 and 45 g day^{-1} higher than the BLS with exception in the LSS (352 g day^{-1}) which was similar to the BLS. As crown cover increased from 10 to 50% the simulated DLWG between scenarios followed similar trends (Figure 8). Depending on the percentage crown cover and type of trees in pastures, the DLWG simulated in the silvopastoral scenarios was between 0.3% and 18% higher than the BLS. The higher DLWG simulated occurred in the MSS at all crown cover percentages with exception at the 10% CC. On the contrary, the lower DLWG simulated were observed in the LSS at all crown cover percentages in comparison with the other silvopastoral scenarios.

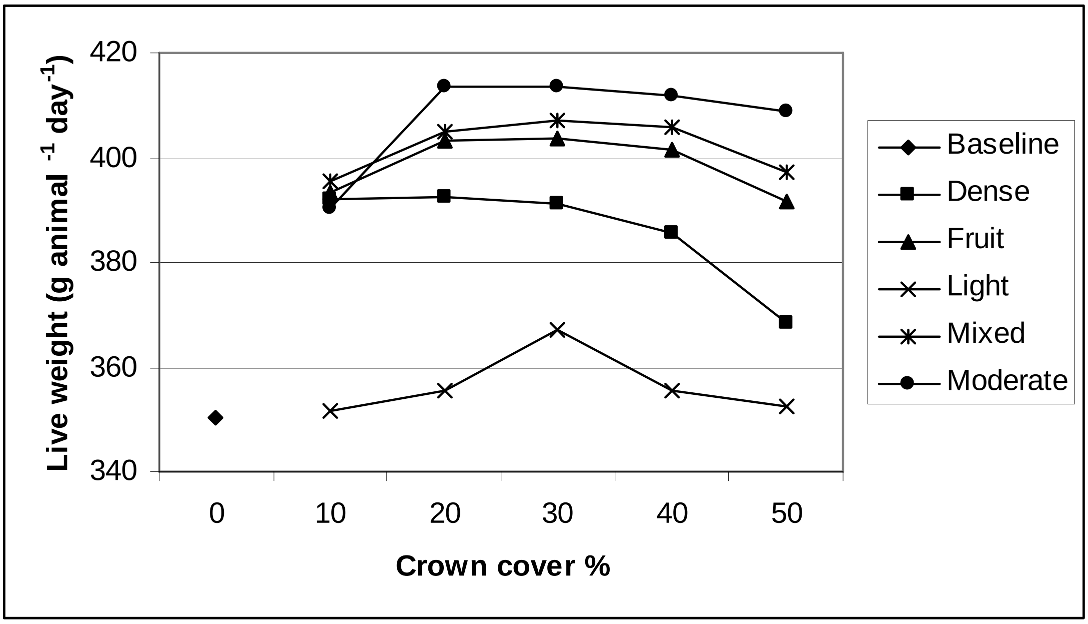

Figure 8. Mean daily live weight gains (average of 365 days growing period) of Zebu steers simulated in the different scenarios in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2006.

Discussion

Simulations performed showed a general reduction pattern of grass DM availability in all silvopastoral scenarios relative to that produced at the baseline scenario (Figure 3). Moreover, grass DM availability was reduced to a larger extent as crown cover increased from 10 to 50% and denser canopy type tree species were considered in the scenarios. It should be noted that generally, a large variability of scattered trees and small cluster of different sizes, characteristics and species composition are present in pastures of cattle farm systems (Esquivel; Chapter III). However, due to the lack of available information about the cluster effects on fodder availability, the model considered the presence of adult isolated individuals from six tree species only. Thus, in the silvopastoral scenario, that included light canopy type tree species (coyol and laurel), grass availability was not reduced greatly as it was reduced in the dense, mixed and fruit bearing tree silvopastoral scenarios that included denser canopy tree species like genizaro, guacimo and Guanacaste. The increased crown cover and denser tree species entailed stronger competition between trees and grasses through intercepting higher solar radiation as well as through increased below ground competition for nutrients and water from which grass DM availability was reduced largely under these conditions. In the same sense, it is expected that the presence of trees in cluster may also entailed stronger competition from which the assumption that all trees occurred in isolation may imply that grass DM availability here modeled was overestimated. Even though trees reduced grass DM availability, current grazing management in the study zone (Restrepo *et al*. 2004) reported that during the wet season, paddocks were rotationally grazed with a mean stocking rate of 1.5 livestock units (LU = 400 kg) ha^{-1}. This mean that, at this current stocking rate pattern, the assumption that one LU consumes approximately 3% DM daily of his body weight, and that grass use efficiency is about 60% (Andrade *et al* 1999), then farmers will need 864 kg of grass DM ha^{-1} month^{-1}. This implies that the grass dry matter produced at any tree cover simulated scenario largely exceeds cattle maximum dry matter intakes estimated.

The presence of fruit bearing tree species, depending on the tree species considered in the scenarios and the crown cover percentage, produced between 45.0 to 75.0% of total fodder available to cattle. However, though trees produced edible fruits for animals, the total fodder biomass was always lower in all silvopastoral scenarios simulated compared to the baseline scenario (Figure 5) but regardless of such situations steers liveweight gains were higher for all silvopastoral scenarios compared to the baseline scenario (Figure 8). Live weight gain simulated in the baseline scenario relates well with data from crossbred Zebu steers grazing pasture monocultures in the dry and semidry tropical environments where daily weight gains ranged from 0.300 to 0.350 kg animal^{-1} day^{-1} (CDI 2006 The general increased DLWG simulated in all silvopastoral scenarios are the result of the fruits produced by trees which provided steers with additional fodder of higher nutrient quality to increase live weight gains suggesting that the higher nutritive quality of fruits, particularly crude protein, offsets the lower grass DM availability caused by trees. This is supported with data of Esquivel *et al* (unpublished) in the same study area which showed that CP of fruits was 12 to 300% and digestibility 37 to 54% higher than that of the associated grass in the silvopastoral system. Silvopastoral scenarios provided cattle between 1.8 and 14.2% higher crude protein than the baseline scenario from which cattle obtained better performance (Figure 8) regardless the lower dry matter availability in these scenarios. Moderate silvopastoral scenario included genizaro trees that in comparison with the other tree species selected produced the fruits with the highest nutritive quality (Table 1) which caused the higher DLWG observed in this scenario at all crown cover percentages with the exception of the 10% CC. This can be explained because, at this crown cover (10%), the low number of individuals (n = 2) present did not provide the adequate amount of fruits to improve animal performance. In the same sense, the combined tree species richness in the mixed, fruit and dense silvopastoral scenarios producing fruits with a varied nutrient quality distributed along the dry season provided a more stable diet to cattle. This allow steers to mitigate their nutritional deficits which contributed to the higher DLWG observed in these scenarios compared with the light and baseline scenarios.). It should be noted that the model does not consider the impacts of trees on mitigating heat stress on animal performance neither considered bypass protein provided by fruits for live weight estimations. In this manner, live weight gains in the simulated silvopastoral systems may be much higher than those here simulated since higher quality nutrients not degraded in the rumen increasing steers voluntary feed intake and hence improving animal performance. The higher cattle performance observed in cattle grazing silvopastoral systems implies that these systems can be managed at lower stocking rate and still provide similar production levels (kg ha^{-1}) than grass monocultures. In addition to this, lower stocking rates will have broader implications since it will contribute to reduce overgrazing, soil erosion and soil compaction which has been some of the main reasons for pasture degradation. It will also contribute to reduce methane emissions to the atmosphere contributing to reverse the negative climate change because the use of *Sapindus saponaria* fruits as a supplement source to sheep feed with tropical grass based diet have prove to reduced daily methane emissions (Heens *et al* 2004). This suggest that the use of fruit bearing tree species in animal feeding could be an environmental friendly way to improve animal performance. Apart from this, trees will also contribute with others products to the farm which will represent an additional income source to farmers. However, there is a need for research to quantify the value of animal and tree products as well as the value for providing environmental services. The generation of this information will be useful for designing silvopastoral systems, particularly in traditional cattle farm systems in which a large mixture of tree species and crown cover percentages generally occurs. Tree diversity studies in traditional cattle farm systems in Cañas (Esquivel *et al*. 2003;) showed that, there are some paddocks (13%) without crown cover whereas others (11%) have less than 15% crown cover and very few (6%) had crown cover in the 20-25% ranges. Moreover, the study showed that 30.6% of paddocks included coyol, guacimo and the timber, laurel and roble, tree species which represented 10.7, 12.6, 12.0 and 12.8 % respectively in relation to the total trees inventoried (n = 5,896) but only 12 paddocks (6.1%) include genizaro and

Guanacaste tree species. This suggest that, although farmers are aware that trees represent an attractive option to increase animal performance and diversify farm income, they need more information about crown cover percentages and tree species that are best suitable to maintain in the paddocks. However, based on the actual low current tree cover pattern found in pastures of cattle farm systems in a dry and semi dry tropical ecosystem (Guevara 1999; Harvey and Haber 2002; Esquivel *et al*. 2003; Villanueva *et al*. 2003; Sanchez *et al* 2005) and in the theoretical improved steer performance simulations here reported it is recommend that farmers increase paddocks tree cover up to moderate (20-25%) crown cover which represent an attractive option to increase animal performance and diversify farm income. Management strategies to achieve this should be focus into the proper selection and combination of tree species. This should include small crown size timber tree species such as laurel and roble but in combination with fruit bearing tree species such as guacimo, genizaro and Guanacaste that besides of reduce grass DM availability at larger extent, produce fruit of high nutritional composition during most of the time of the dry period that important to improve cattle performance. Increasing farm tree cover not only will provide cattle with additional fodder of higher nutritive quality, but it will contribute to farms sustainability throughout a multifunctional land use options (Devendra *et al*. 2004) and to farm productivity and profitability thought tree products and services (Beer *et al*. 2000). Trees produce firewood, fruits and timber among other products from which farmers could diversify farm products and generate additional farm incomes. Morales and Kleinn (2000) reported that between 40 to 50% of total timber volume processed during 1990-1995 in Costa Rica came up from timber trees in pastures and Souza de Abreu *et al*. (2003) reported that *Cordia alliodora* timber tree specie dispersed in pastures of cattle farms in Costa Rica represented 1% to the total gross farm income which contribute to diversify cattle farm income. From the environmental point of view trees provide environmental services (i.e. carbon sequestration, watershed protection and conserve biodiversity) and contributes to soil improvements lessening the rapid pasture degradation from which farmers can increase their land value. Efforts in exploring the proper combinations and cover percentages of tree species dispersed in pastures by modeling should be continued to respond farmers concerns about the “apparent” incompatibility between trees and pastures and to show the importance of the role that trees play in pastures. The inclusion of trees in pastures apart of technical advice requires a high initial investment which most farmers cannot afford (Teklehaimanot *et* *al*. 2004). Therefore there is a need to formulate and implement policies and conditions that favor tree planting in cattle farms. Such policies should include land, environmental, credit and tax policies as well as subsidies, incentives and regulations that allow farmers to increase tree cover dispersed in their pastures. Preliminary results from a study case in Central America (Ibrahim 2005 pers. comm.) have shown that when adequate policies and incentives (i.e. environmental services payments) are formulated and promoted among cattle farmers, planting trees in different arrangements (fodder shrubs, live fences and dispersed or clustered trees) in pastures of cattle farm systems is feasible for sustainable livestock production and environmental wellbeing.

Conclusion

Simulation performed showed that there was a reduction in the amount of available forage to cattle with different percentage of tree cover and tree types based on the crown density and whether they were fruit bearing trees. This effect was greater for high tree cover percentages and denser tree crown types. However, the amount of energy and protein produced by fruit bearing tree species in silvopastoral mixtures such as in the mixed, moderate and fruit scenarios was higher to that observed for the baseline scenario indicating that a loss in available pasture was compensated with the production of fruits of high nutritional quality. In the high tree cover with only fruit bearing trees (fruit silvopastoral scenario), the amount of energy and protein produced by the fruits represented 35.2 and 45.7% of total production in the systems and this has much relevance in animal production especially since the fruits are produced during the dry seasons where there is lack of high quality grass available to cattle. Live weight gains simulated in all silvopastoral systems were higher than that simulated in the baseline scenario and this shows the potential of these systems to improve animal productivity and diversify farm income. Although more research is need about tree cover percentages and species composition that are best suitable to include in paddocks of cattle farms, it is recommended that farmers increase paddocks crown cover up to moderate (20-25%) crown cover including a mixture of timber tree species with the crown carachterisctis of laurel and roble combined with multipourpose tree species that produced large amount of fruits of high nutritional quality but maintaining 1 or 2 individuals from tree species that reduced grass DM availblity largely.

CHAPTER VI

GENERAL DISCUSSION CONCLUSSIONS AND RECOMMENDATIONS

General discussion

Many studies have highlighted the benefits of tress to cattle farm systems. These include reductions in soil erosion increased soil fertility, improved microenvironmental conditions under tree canopies reducing air temperatures and wind speed favoring pasture and cattle production. Another aspect associated with trees is the potential to provide additional fodder of higher nutritional quality than grasses apart from shade and shelter to cattle. However, the extents of these benefits largely depend on species, densities, configuration and characteristics from trees present in paddocks. While these studies provide solid basis for the inclusion of trees in cattle farm systems, very few studies have focuses on characterize tree cover and density occurring in pastures of cattle farm systems and much less in evaluating how this tree cover and densities impact livestock productivity. Therefore knowing how tree cover varies across farm types, what factors contribute to patterns of tree species distribution within the pastures, how this tree cover affects standing herbage biomass of pastures and how the fruits produced from these tree species contributes to improve cattle farm systems takes relevance for the better understanding of the interactions between the components that allow for better design of silvopastoral systems. This research, conducted in a dry tropical ecosystem in Costa Rica, show that most farms in Cañas, Guanacaste, are characterized by *Brachiaria brizantha* grass species paddocks with scattered dispersed isolated trees and small clusters left behind after sowing the paddocks. The tree inventory conducted in 196 paddocks showed that there were 99 tree species belonging to 33 families dispersed in pastures of cattle farm systems, but six trees species; laurel (*Cordia alliodora*), roble (*Tabebuia rosea*) and cortez amarillo (*Tabebuia ochracea*) coyol (*Acrocomia aculeata*) guacimo (*Guazuma ulmifolia*) and nance (*Byrsonima crassifolia*) were the most abundant and frequent tree species found dispersed in pastures. These six tree species corresponded nearby to 60% of total species inventoried whereas 19 species were represented by only one tree and seven species by two individuals. The abundance and diversity of tree species found dispersed in pastures suggest that farmers prefer to maintain small and light crown type tree species such as timber tree species laurel and roble in pastures compared to large and dense tree canopy types (*Ficus spp*, *Mangifera indica*) in order to minimize pasture reduction, although fruit bearing tree species like guacimo, genizaro and Guanacaste are maintained in pastures regardless of their crown types to provide cattle with additional fodder source during the dry season. However, farmers` preferences to favor some particular tree species over others, represents a risk of loosing some valuable tree species as suggested by the low abundance of some tree species found. Dispersed trees in pastures showed an asymmetric dbh distribution where individuals were concentrated in the 20 to 60 cm dbh category (Figure 2). A low number of trees in the lowest dbh category (10 – 20 cm) indicated a low rate of natural regeneration which may be associated with pasture management practices such as weed control, grazing regimen and stocking rates.

Most farms paddocks were categorized without tree cover and with low crown cover (< 15%) and tree density (15 trees ha^{-1}) whereas very few paddocks have larger densities and cover. Tree crown cover and density were associated with different farm types, which were higher in small beef cattle farms than in the other farm types. These parameters however, varied largely among paddocks within the same farms as well as between farm types. Tree density and crown cover variations were related with tree and paddocks characteristic. A clear trend of increasing density and cover occurred as paddock/farm size was decreased, paddock slope was increased and higher tree species diversity occurred. These findings suggest that farmers are managing small pastures/farms in a more intensified way increasing the multifunctional role of pastures in order to diminish external risks of cattle enterprises and secure incomes through out selecting different tree resources. Even though, tree density and tree cover were higher on small beef cattle farms and the large variability found, diversity and similarity indices were not different between farm types. Main reason for this can be attributed to the similar land use history, land charactersitcs as well as to the similar topographic and environemtal conditions in the study area indicating that farmers maintain in their farms the same tree species useful to them and to cattle.

The study of the impacts of tree cover on fodder quantity and quality showed that paddocks with moderate (10 – 15%) tree cover composed by a mixture of tree species favored the availability of the understorey vegetation. This can be explained by the fact that moderate shade levels confers pastures with improved microenvironmental conditions inducing and increased biomass production of the grass growing under the shade compared with same grass species growing in the open grassland (Ovalle and Avendaño 1988; Belsky et al., 1993; Andrade et al., 1999). Improved microenvironmetal conditions include wind speed, air temperatures and soil humidity lowering the evaporative demand of grasses improving its water status, particularly during the dry season (Dulornme et al., 2004). Shade from trees improves the nutritional quality of pastures, particularly crude protein, as this was higher at shade underneath all tree species crowns studied than at full sunlight. Improvements in grass nutritional quality have been suggested to be due higher nitrogen mineralization rates as well as to morphological and physiological changes that plants growing under shade environments adopt. Another mechanism that can explain higher CP of forage growing under trees is an increase in soil fertility caused by higher organic matter and nutrients through litter fall and N fixation.

In contrary to the beneficial effect caused by moderate tree cover (< 20%) on paddock standing herbage biomass, high shade levels (>25%) decreased standing herbage biomass and broad leaves weeds are dominant. suggesting that these light conditions are not favorable for the growth of *Brachiaria brizantha* grass species. In the same sense, individual tree species that intercept more than 40% of the incoming light (high shade levels) affected negatively grass underneath their canopies reducing the standing herbage biomass at individual basis. These effects however, are very species specific depending on crown size and tree characteristics. Thus, tree species with large and dense tree crowns like guacimo and Guanacaste reduced standing herbage biomass to a larger extent than smaller and lighter tree canopies such as coyol and laurel which allowed more solar radiation to reach the understorey.

One of the main problems that cattle farmers face in the dry and semi dry regions is the high variability of forage availability and quality due to seasonal dry periods causing poor animal performance. This research clearly shows the great potential that dispersed trees in pastures have to outweighing grass shortages by the provision of additional fodder of high nutritional quality available to cattle during the dry season improving animal performance. Fruit bearing tree species produced up to 86 kg of fresh fruit per tree on seasonal basis. Some tree species like Guanacaste produced 10 times more fruits than coyol trees, but fruit production per crown square meter was similar between the all tree species of this study and fruit bearing tree species produced fruits of higher nutritive quality than grasses. Fruit inclusion in cattle diets has contributed to increased cattle productivity in farm systems based on pastures. Live weigh changes simulated showed that steers grazing silvopastoral scenarios gained more weight than steers grazing monoculture pasture plots placing special attention into the proper selection and combination of tree species and densities.

It seem, from tree species abundance and diversity found dispersed in pastures of cattle farm systems and from their impacts observed in pasture availability, that farmers are managing tree cover of pastures to maintain a mixture of tree species to fulfill different needs based on the visual grass reduction caused by trees rather than on the less tangible benefits that trees provide to cattle. Thus timber tree species with smaller tree crowns such as roble and laurel are found at higher densities because these tree species are highly valued by farmers and they do not reduce pasture availability compared with large and dense crowns tree species such as genizaro and Guanacaste that are maintained in low densities to provide shade, shelter and high nutritive quality fruits to cattle to overcome dry season nutritional deficits, but to minimize reduction in pasture productivity. However, simulation showed that besides grass DM reductions, the large genizaro and Guanacaste tree species produces high nutritional quality fruits during the critical time within the dry season but these tree species are maintend at low densities in pastures because tree benefits are often eclipsed by the competitive effects with pastures for space and resources (i.e. nutrients, water and light). However the fact that most paddocks are sowed with the improved *B. brizantha* grass specie that can support higher tree cover than the actual low current tree cover (<15%) pattern found in pastures and the theoretical improved steer performance simulations here reported represent an attractive option to increase livestock productivity in the dry and semidry tropical areas by increasing paddocks crown cover with the inclusion of a mixture of tree speicies. Although most farmers are aware about the benefits that different tree species provide to pasture, as shown by the tree species diversity that they maintain in pastures, they need more information about the contribution that large crown fruit bearing tree species have to pasture and animal productivity. Management strategies to achieve this should be focus in formulate and implement policies and condition like land, environmental, credit and tax policies as well as subsides, incentives and regulations that allow farmers to increase tree crown cover dispersed in their pastures up to moderate (20-25%) levels including a mixture of tree speices of different size and charactaresticas that provide famrs with a varied source of products from which farmers can improve cattle famr productivity ans sustainability.

General conclusions

A total of 99 tree species were found dispersed in 196 pasture plots (835 ha) of 16 cattle farm systems in the dry tropic ecosystem in Cañas, Costa Rica. However six species, *Tabebuia rosea*, *Guazuma ulmifolia*, *Cordia alliodora*, *Acrocomia aculeata*, *Byrsonima crassifolia* and *Tabebuia ochracea* were found to dominate the landscape fragmented by cattle farms since they represented near 60 % of total tree inventoried (n = 5,896).

Small beef cattle farms (< 50 ha) maintain higher crown cover and tree density than mixed farms (beef and agriculture) and larger beef cattle farms, (> 51 ha) suggesting that farmers with small farms are using pastures in a more intensified way increasing the multifunctional role of pastures in order to diminish external risks of cattle enterprises and secure incomes through different tree resources

Tree species with large and dense crown types (i.e. *Samanea saman*, *Enterolobium cyclocarpum*) growing in isolation permitted low light transmission under their crowns, reducing standing herbage biomass at higher extent than trees with open and smaller crown types, such as *C. alliodora*, *T. rosea* and *A. aculeata*. However, the former tree species are maintained at low densities to provide additional fodder to cattle and not interfere with pasture productivity.

Standing herbage biomass harvested at pasture level increased as tree cover was increased from 0 to 16%, followed by a decrease in biomass as crown cover increased above this percentage. This effect is attributable to the microenvironment benefit effects that shade provide to pastures in dry and semi dry tropical ecosystems.

High abundance of broad-leaved weeds was found at shade levels > 30% suggesting that growth and production of *B. brizantha* was limited by these light conditions.

Standing herbage quality, particularly crude protein, was increased underneath tree canopies compared to that at full sunlight. Additionally, fruits of tree species collected in this study provide additional fodder of higher *In vitro* dry matter digestibility (> 63%) and crude protein (> 8%) than *B. brizantha* grass specie during the critical dry periods. Simulations performed implies that farmers can increase tree cover of *B. brizantha* pasture plots in a tropical dry ecosystem with the inclusion of multipurpose tree species that produce high quality fruits available to cattle without sacrifice livestock production.

The greater fodder quality available to cattle in silvopastoral plots producing fruit to cattle offset the lower cumulative forage production caused by trees, and this provided greater beef cattle liveweight gains compared to cattle grazing *B. brizantha* monocultures pasture plot.

Although much work is still required in order to parameterize and validate the model, insights were draw into the role that moderate (20-30%) cover of pasture plots with tree species that produce high nutritive quality fruits had on improving cattle liveweight gains regarding the reduced grass biomass available. I believe that these insights, even if they are not completely accurate, are useful because highly the need to conduct research regarding specie-cover combination for the better design of silvopastoral systems.

The results found emphasizes the importance of considering the contribution of dispersed trees in pastures had on livestock productivity of traditional silvopastoral systems rather than considering the isolated individual effects of tree species had upon grasses since the net effect of tree cover to cattle farm systems is a function not only of which tree species are present, but also at what densities and arrangements they occur.

The study highly the urgent necessity for designing incentive schemes and policies that promotes tree planting and conserve tree resource in agricultural landscape dominated with cattle that serve to lesser deforestation, improve animal productivity and provides a varied habitat for a wide range of species.

Recomendations

Additional research with disperse trees in pastures should be continued incorporating spatial distribution and arrangements of trees in pastures as well as different stocking rates and grazing management regimes since all of them influence grass dry matter productivity.

The lack of enough number of replicates above 15% of tree cover highlight the importance to conduct additional research in pasture plots with moderate to high (20-30%) crown cover to support the findings reported in this research.

Research in order to classify and categorize the different tree species present in pastures in terms of light interception or crown canopy type and explore their effect on grass dry matter productivity should be promoted.

It is necessary to conduct research evaluating fruit production from different tree species and provenances to measure the inter and intra yearly fruit variability with the objective to identify tree species provenances suitable to livestock productivity.

Research looking for the main political, socioeconomical and technical constraints limiting to increase disperse tree cover in pastures, particularly those tree species with the potential to mitigate fodder shortage, are needed to promote tree planting in pastures of cattle farms.

There is a need to conduct productive and economic studies considering the different roles that scattered dispersed trees in pastures play in cattle farms productivity to respond farmers concerns about the apparent incompatibility between trees and pastures.

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Appendix 1 List of all tree species found dispersed in paddocks of the 16 cattle farms inventoried in Cañas, Guanacaste, Costa Rica, 2003. Data are organized in decreasing order of number trees registered

Family	Scientific name	Species code	Main tree uses	Number of trees recorded
Bignoniaceae	*Tabebuia rosea* (Bertol.) DC. In A. DC.	TABROS	Timber	756
Sterculiaceae	*Guazuma ulmifolia* Lam.	GUAULM	Forage	742
Boraginaceae	*Cordia alliodora* (Ruiz & Pav.) Oken	CORALL	Timber	707
Arecaceae	*Acrocomia aculeata* (Jacq.) Lodd. ex Mart.	ACRVIN	Forage, Fruit	632
Malpighiaceae	*Byrsonima crassifolia* (L.) Kunth in Humb,; Bonpl. & Kunth.	BYRCRA	Fruit	434
Bignoniaceae	*Tabebuia ochracea* (A.H. Gentry) A.H. Gentry	TABOCH	Timber	265
Bombacaceae	*Pachira quinata* (Jacq.) W.S. Alverson	BOMQUI	Timber	183
Papilionaceae	*Andira inermis* (W. Wright) Kunth ex DC.	ANDINE	Timber	169
Papilionaceae	*Piscidia carthagenensis* Jacq.	PSICAR	n/a	158
Fabaceae	*Acosmiun panamense* (Benth.) Yakovlev	ACOPAN	Timber	140
Burseraceae	*Bursera simaruba* (L.) Sarg.	BURSIM	Forage	127
Moraceae	*Maclura tinctoria* (L.) Steud.	MACTIN	Timber, Fruit	98
Lauraceae	*Ocotea veraguensis* (Meisn.) Mez, Jahrb. Koningl	OCOVER	n/a	97
Caesalpiniaceae	*Hymenea courbaril* L.	HYMCOU	Timber	82
Anacardaceae	*Spondias purpurea* L.	SPOPUR	Fruit	81
Mimosaceae	*Samanea saman* (Jacq.) Merr. (=*Albizia saman*	SAMSAS	Timber, Forage	77
Papilionaceae	*Myrospermum frutescens* Jacq.	MYRFRU	Timber	74
Meliaceae	*Cedrela odorata* L.	CEDODA	Timber	67
Papilionaceae	*Gliricidia sepium* (Jacq.) Steud.	GLISEP	Forage	58
Papilionaceae	*Lonchocarpius felipei*	LONFEL	n/a	58
Mimosaceae	*Enterolobium cyclocarpum* (Jacq.) Griseb.	ENTCYC	Timber, Forage	57
Moraceae	*Ficuss spp*	FICSPP	n/a	52
Caesalpiniaceae	*Caesalpinia eriostachys* Benth.	CAEERI	n/a	48
Myrtaceae	*Eugenia salamensis* (Standl.) Mc Vaugh	EUGSAL	Fruit	47
Anacardaceae	*Mangifera indica* L.	MANIND	Fruit	47
Papilionaceae	*Dalbergia retusa* Hemsl.	DALRET	Timber	44
Mimosaceae	*Lysiloma divaricatum* (Jacq.) J.F.	LYSDIV	Timber	37
Rutaceae	*Citrus sinensis* (L.) Osbeck	CITSIN	Fruit	35
Meliaceae	*Swietenia macrophylla* King, Hooker's	SWIMAC	Timber	31
Rutaceae	*Citrus limon* L.	CITLIM	Fruit	29

Lauraceae	*Persea americana* Mill.	PERAME	Fruit	22
Anacardaceae	*Spondias mombin* L.	SPOMOM	Fruit	22
Rutaceae	*Zanthoxylum cetulosom*	ZANCET	n/a	21
Myrtaceae	*Psidium guajaba* L.	PSIGUA	Fruit	20
Chrysobalanaceae	*Licania arborea Seem.*	LICARB	na	19
Anacardaceae	*Anacardium occidentale* L.	ACAOCC	Fruit	18
Rubiaceae	*Genipa americana* L.	GNEAME	Timber	17
Tiliaceae	*Luehea espaciosa* (Moc¸. & Sesse` ex DC.)	LUESPA	Timber	17
Papilionaceae	*Diphysa Americana* (Mill.) M. Sousa	DIPAME	Timber	16
Mimosaceae	*Pseudosamanea guachapele*	PSEGUA	Timber	16
Caesalpiniaceae	*Cassia grandis* L.	CASGRA	n/a	15
Bignoniaceae	*Godmania aesculifolia*	GODAES	n/a	15
Caesalpiniaceae	*Schizolobium parahyba* (Vell.) S.F. Blake	SCHPAR	Timber	15
Chrysobalanaceae	*Couepia polyandra* (Kunth) Rose	COUPOL	Fruit	13
Papilionaceae	*Lonchocarpius costarricences*	LONCOS	Timber	13
Rutaceae	*Citrus limettoides* L.	CITLIE	Fruit	11
Meliaceae	*Trichilia havanensis*	TRIHAV	Fruit	11
Sapindaceae	*Cupania guatemalenses* (kunth) Rose	CUPGUA	n/a	10
Anacardaceae	*Anacardium excelsium* (Bertero & Balb. ex) Kunth Skeels	ANAEXC	Timber	9
Anacardaceae	*Astronium graveolens* Jacq.	ASTGRA	Timber	9
Bignoniaceae	*Crescentia alata Kunth in* Humb.; Bonpl. & Kunth	CREALA	n/a	9
Annonaceae	*Annona reticulata* L.	ANORET	Fruit	8
Arecaceae	*Cocus nucifera*	COCNUC	Fruit	8
Caesalpiniaceae	*Tamarindus indica* L	TAMIND	Fruit	8
Rutaceae	*Citrus aurantium* L.	CITAUR	Fruit	7
Polygonaceae	*Coccoloba caracasana Meisn*. In A. DC.	COCCAR	Fruit	7
Verbenacea	*Gmelina arborea* Roxb. ex Sm. in Rees	GMEARB	Timber	7
Verbenacea	*Rehdera trinermis*	REHTRI	n/a	7
Sapindaceae	*Sapindus saponaria* L.	SAPSAP	n/a	6
Bignoniaceae	*Tabebuia impetiginosa* (Mart. ex DC.) Standl.	TABIMP	Timber	6
Sabiaceae	*Chrysophyllum caimito*	CHRCAI	Fruit	5
Rutaceae	*Citrus mitis* L.	CITMIN	Fruit	5
Papilionaceae	*Erythrina spp.*	ERISPP	n/a	5

Bombacaceae	*Ceiba pentandra* (L.) Gaertn	CEIPEN	n/a	4
Rutaceae	*Citrus paradisi* L.	CITPAR	Fruit	4
Mimosaceae	*Abarema macradenia* (Pittier) L. Rico	ABAMAC	n/a	3
Cecropiaceae	*Cecropia spp*	CRESPP	n/a	3
Papilionaceae	*Dipterix panamensis*	DIPPAN	Fruit	3
Sapotaceae	*Manilkara zapota (L.) P. Royen*	MANZAP	Fruit	3
Sapindaceae	*Melicocca bijuga* L.	MELBIJ	Fruit	3
Sterculiaceae	*Sterculia petala*	STEPET	Timber	3
Moraceae	*Trophis racemosa*	TRORAC	Fruit	3
Annonaceae	*Annona purpurea* Moc¸. & Sesse´ ex Dunal	ANNPUR	Fruit	2
Rubiaceae	*Calycophyllum candidissimum* (Vahl) DC.	CALCAN	n/a	2
Boraginaceae	*Cordia panamensis*	CORPAN	Timber	2
Caesalpiniaceae	*Delonix regia (*Bojer ex Hook.) Raf. Fabaceae/	DELREG	n/a	2
Flacourtaceae	*Laetia thamnia* L.	LAETHA	n/a	2
Tiliaceae	*Luehea candida* (Moc¸. & Sesse` ex DC.)	LUECAN	Timber	2
Cecropiaceae	*Pourouma minor*	POUMIN	n/a	2
Leguminosae	*Acacia farnesiana* (L.) Willd.	ACAFAR	Fruit	1
Tiliaceae	*Apeiba tibourbou Aubl.*	APETIB	n/a	1
Cochlospermaceae	*Cochlospermum vitifolium* (Willd) Spreng.	COCVIT	n/a	1
Boraginaceae	*Cordia greascanthus*	CORGRE	Timber	1
Papilionaceae	*Dussia macroprophyllata*	DUSMAC	Timber	1
Rutaceae	*Murraya paniculata*	MURPAN	n/a	1
Arecaceae	*Palma spp*	PALSPP	Fruit	1
Mimosaceae	*Phithecellobium hymeneaefolium*	PHIHYM	n/a	1
Sapotaceae	*Pocteria campechiana*	POCCAM	Fruit	1
Annonaceae	*Sapranthus palanca Fries*	SAPPAL	n/a	1
Fabaceae	*Senna papillosa* (Britton & Rose) H.S. Irwin & Barneby	SENPAP	n/a	1
Sapotaceae	*Sideroxylon capiri* (Pittier) T.D. Penn.	SIDCAP	Timber	1
Elaeocarpaceae	*Sloanea terniflora* (Moc. ex Sesse ex DC.) Standl.	SLOTER	n/a	1
Mimosaceae	*Stryphnodendron excelsum Harms*	STREXC	Timber	1
Polygonaceae	*Triplaris melaenodendon*	TRIMEL	n/a	1

Appendix 2 List of all paddock descriptors and tree chararcteristics variables used in the multiple regression model in relation to crown cover and tree density (dependent variables) in pastures (n = 196) of cattle farms in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica, 2003.

Variable	code	unit
Crown cover	CC	%
Tree density	TD	n ha^{-1}
Number of plots per farm	P/F	n
Plot size	Sz	ha
Mean slope plot	S	%
Man plot heigh above sea level	Z_POLY	%
Height above ground at the location of the shortest distance to the river	Z_RIOS	m
Distance to primary human settlement -- settlement with market function (Canas)	D_AH1	m
Distance to the next human settlement	D_AH2	m
Distance to the next river	D_RIOS	m
Shorest plot distance to the main road	D_CAM1	m
Shorest plot distance to the internal farm road	D_CAM2	m
Life fence cover	LFC	%
Mean tree height	Th	m
Mean diameter at breasth height	DAP	cm
Pasture type (Improved / Naturalizad)	Pt	

Appendix 3. Model assumptions

Paddocks are of one hectárea size
Paddocks are sown with *Brachiaria brizantha* grass species
Paddocks include only six tree species at the most
Tree cover is randomly dispersed in paddocks
Trees occur as isolated adult individuals
No crown cover overlap occur
All individuals from the same tree species are of the same since (no tree growth occur)
All individuals from the same tree species produce the same fruit amounts
Paddock stocking rate was 1.5 steers ha^{-1}
One livestock unit equals 400 kg
Maximum DM intake per $animal^{-1}$ day^{-1} was estimated to be 3% of body live weight.
Steers intial liveweight was set to 200 kg
Fruits are considered as supplements
Suplements are eat first
Maximum 30% of animal diet was provided by fruits.