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STANDING HERBAGE BIOMASS UNDER DIFFERENT TREE SPECIES DISPERSED IN PASTURES OF CATTLE FARMS

[DISPONIBILIDAD DE BIOMASA FORRAJERA BAJO DIFERENTES ESPECIES ARBÓREAS DISPERSAS EN POTREROS DE FINCAS GANADERAS]

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SUMMARY

The study conducted in a tropical dry ecosystem at Cañas, Guanacaste, Costa Rica (10^o 11´ N and 84^o15´W) measure the standing herbage biomass (SHB) availability and quality under six isolated tree species of different canopy architecture dispersed in active *Brachiaria brizantha* pastures and compare it to that growing at full sun light. Standing herbage biomass (HB) harvesting and Photosynthetic active radiation (PAR) readings were taken at three different periods in a paired sample scheme. Of the six tree species studied, *Enterolobium cyclocarpum* had the largest mean crown cover while *Acrocomia aculeata* had the smallest. Significant differences were observed between species (P = 0.0002) and seasons (P<0.008) for the percentage of PAR transmitted under the canopy but PAR levels obtained under all species were consistent throughout seasons since the interaction between species and season was not significantly different (P=0.98). Lower PAR readings (<50%) were taken under the canopies *E. cyclocarpum* and *Guazuma ulmifolia* (21.7 and 33.7 % respectively). Standing herbage biomass (SHB) harvested under the crown of isolated mature individual tree species was significantly lower (P<0.001) than in open pasture areas for all tree species except that of *A. aculeate* but SHB crude protein content, was higher underneath all tree canopies. It can conclude that light reduction caused by tree canopies reduces SHB availability and increases the quality underneath tree canopies compared to areas of full sun but these varies accordingly to tree species and seasons.

Key words: *Brachiaria brizantha*; dry tropics; photosyntetic active radiation; silvopastoral systems; tree canopy architecture.

RESUMEN

El estudio, realizado en un ecosistema tropical seco en Cañas, Guanacaste, Costa Rica (10^o 11´ N and 84^o15´W) midió los efectos del tipo de copa sobre la disponibilidad de biomasa forrajera y su calidad creciendo bajo la copa de los árboles aislados comparada con aquella creciendo a pleno sol. Se midió la Disponibilidad de Biomasa (SHB) y la Radiación Fotosintéticamente Activa (PAR) durante tres diferentes periodos mediante un esquema pareado. De las seis especies arbóreas estudiadas, *Enterolobium cyclocarpum* tuvo la mayor cobertura de copa (m^2) mientras que *Acrocomia aculeata* tuvo la menor cobertura. Los resultados mostraron diferencias estadísticas (P = 0.0002) entre especies y épocas (P < 0.008) para PAR transmitido bajo de la copa de los árboles, los cuales fueron consistentes durante las diferentes épocas. Se obtuvieron lecturas de PAR < 50 % bajo la copa de *E. cyclocarpum* and *Guazuma ulmifolia* (21.7 and 33.7 % respectivamente). La biomasa disponible cosechada bajo la copa de los árboles fue significativamente menor comparado con la disponible a pleno sol para todas las especies excepto para *A. aculeata*, pero la proteína cruda de la biomasa fue mayor bajo la copa de todas las especies comparada con la de pleno sol. Se concluye que la reducción solar causada por la copa de los árboles reduce la biomasa y aumenta la calidad disponible bajo su copa cuya variación depende de del tipo y tamaño de copa así como de la época.

Palabras clave: *Brachiaria brizantha*; trópico seco; radiación fotosintecamente activa; sistemas silvopastoriles; arquitectura de copa.

INTRODUCTION

Latin America and the Caribbean account for the largest percentage of net forest losses (United Nations, 2009), most of which, has been converted to grass monocultures to establish extensive livestock production systems, occupying nowadays more than 27 % of Latin America rural landscape (FAO, 2009). Pasture establishment, largely encouraged by policy makers, has been harmful to the environment causing deforestation, soil erosion, land fragmentation, desertification and pasture degradation with consequent environmental damage, global warming through the production of green house gases (GHG) and loss of biodiversity (Timon, 2004; FAO, 2005). As cattle ranching is not likely to decline in the near future in Latin America the use of silvopastoral systems (SPS) that incorporate dispersed native trees into cattle farm ranching is a key strategy to reversing this situation (Murgueito *et al*., 2011). Dispersed trees in SPS pastures can be defined as that where multi-species trees are found in a non systematic arrangement (either isolated or in clusters) within the pastures, where 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. Many authors have shown that trees provide benefits to cattle farms and to the environment (Gibbons and Boak, 2002; Teklehaimanot *et al.*, 2002; Murgueito *et al*., 2011). Trees can provide farmers with additional non - cattle products like timber, fence posts, firewood 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). Traditional silvopastoral systems in seasonally dry areas are characterized with multipurpose trees (e.g. *Guazuma ulmifolia, Samanea saman,* Jacq., *Enterolobium cyclocarpum, Leucaena leucocephala, Prosopis juliflora*) dispersed in pastures producing fodder of higher nutritive value than the associated grass species, especially during the dry season (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 systems that use external supplements during the dry season to feed cattle. Although some studies concerning tree-pasture relationships in dry tropical areas have been published, there is still uncertainty concerning the extent to which standing biomass yield and quality are affected by different tree species. Local knowledge (Stokes, 2001; Muñoz *et al*., 2003) and decision making (Villanueva *et al*., 2003a; León, 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 understory vegetation (Muñoz *et al*., 2003). Thus, understanding how tree species affects pasture production at different seasons will help farmers to select the more suitable tree species. The objective of the study, conducted as a pilot study under field conditions, was to measure the standing herbage biomass (SHB) availability and quality under six isolated tree species of different canopy architecture dispersed in active *Brachiaria brizantha* paddocks and compare it to that growing at full sun light.

MATERIALS AND METHODS

Study site

The study was conducted in four active *B. brizantha* paddocks at a livestock farm located in Cañas, Guanacaste, Costa Rica (10^{o} 11´ N and 84^{o}15´ W). The study area is classified as a tropical dry forest (Holdridge, 1978) with elevations ranging from 60 to 250 m asl (Arauz, 2001). Average temperatures, rain fall and relative humidity is show in figure 1 (Taboga Meteorological Station, 2003). Soils in the lowlands are of volcanic origin and are mainly vertisols with an average depth of 100 cm. In the uplands 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 size ranged from 18 to 241.3 ha, with an average of 67.0 ha whereas paddock size varied from 0.1 to 39.5 ha. Most of the farm paddocks contained improved or introduced grass species, among which, *B. brizantha* and *Brachiaria decumbens* were the most common while *Hyparrhenia rufa* and *Paspalum* spp were the most frequent naturalized/native grass species. 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 and tree density varied from 0 to 68 trees ha. Paddock size ranged from 1.2 to 7.5 ha. In the dry season, paddocks were continuously grazed at an average stocking rate (SR) of 1.2 head ha. During the wet season, paddocks were rotationally grazed with 4 to 30 day grazing periods and 30 to 50 days resting periods. The SR during the wet season ranged from 1.1 to 1.3 head ha.

Tree species selection and measurements

Previous tree inventory data (Esquivel *et al.*, 2003) were used to select the four most abundant tree species *Acrocomia aculeate* (Jacq.) *Cordia alliodora* (Ruiz & Pav) Oken, *Guazuma ulmifolia* Lam, *Tabebuia rosea* (Bertol) and two of the largest crown tree species *Enterolobium cyclocarpum* (Jacq.) Griseb. and *Samanea saman* (Jacq.) Merr. were dispersed in 60 active paddocks of *Brachiaria brizantha* in 16 livestock farms. However, the tree inventory showed that the presence of these tree species varied greatly between paddocks (some paddocks did not have any isolated individuals from a particular tree species selected); therefore this approach resulted in four *B. brizantha* paddocks being selected which contained an unbalanced tree species distribution within them (Table 1). 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. Tree crown was measured from the readings of two perpendicular measurements covering the longest axes of the crown (Below and Nair, 2003) and crown cover was calculated using the ellipse formula $A = (\pi * R1 * R2)$.

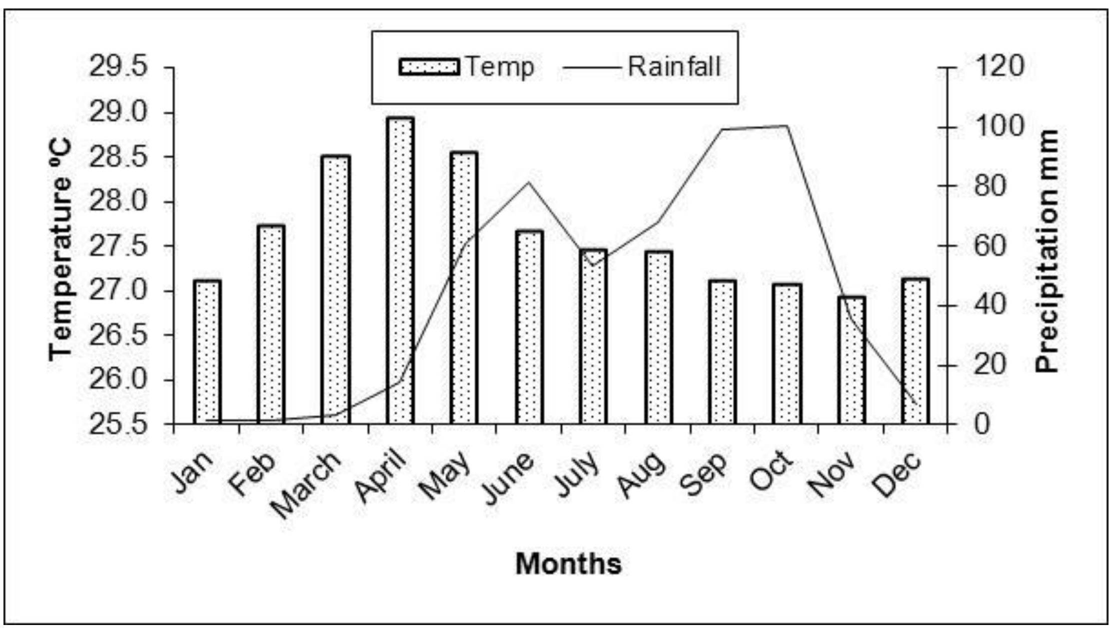

Figure 1. Monthly average temperature and rain fall in the study zone during the study year

Table 1. Mean structural variables for each of the six isolated tree species found dispersed in four active *Brachiaria brizantha* paddocks in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica.

Tree species	Trees (n)	dbh (SE)	Height (SE)		CC[$]	PAR, %, (SE)
		(cm)	Total (m)	Bole[φ] (m)	(m^2 $tree^{-1}$)	Transmitted
A. aculeata	9	36.4 (1.6)a	9.8 (0.5)a	na	19.5 (1.2) a	60.5 (6.0) c
C. alliodora	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
E. cyclocarpum	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
G. ulmifolia	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
S. saman	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
T. rosea	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; [φ] = 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 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 during sunny days between 12:00 and 14:00 h 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 cover, 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 understory vegetation was expressed as a percentage and was calculated as PAR Shaded / PAR Open * 100.

Standing herbage biomass sampling

In order to quantify the availability and quality of SHB under tree canopies and compare it to that standing at full sun light, SHB was sampled 21 $\pm$ 5 days after Zebu cattle were removed from the paddock to allow pasture recovery. Standing HB samples were taken in three quadrates (0.5 x 0.5 m; t`Mannetje, 2000) randomly placed under tree canopy and three quadrates outside the canopy by cutting the vegetation to ground level and weighing it in the field. Afterwards, the three samples collected from each zone were mixed to form a composite sample according to zone 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 and sent to laboratory to analyze 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). Measurements were performed once during the early dry period (December to January), once during the late dry period (March to April), and once during the early rainy period (June to July).

Data analysis

One way analysis of variance (ANOVA) was performed to test for differences between tree structural characteristics of 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 treatment means were compared using the 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. All data were checked for normality and variance homogeneity using a Shapiro-Wills and Levene test, respectively. All analyses were performed using InfoStat 4.1 (2004).

RESULTS

Tree species characteristics

Of the six species studied, *E. cyclocarpum* had the largest mean crown cover whereas *A. aculeata* had the smallest . *Samanea saman* had the second largest mean crown cover, which was significantly larger than *G. ulmifolia*, *C. alliodora*, *T. rosea* and *A. aculeata*. Mean diameter at breast height and total height of *E. cyclocarpum* trees were larger than for the other species, whereas mean bole height was similar among all species (Table 1).

Light transmission

Significant differences were observed between species ($P = 0.0002$) and seasons ($P < 0.008$) for the percentage of PAR transmitted under the canopy (Figure 2) but PAR levels obtained under all species were consistent throughout seasons as the interaction between species and season was not significant ($P = 0.98$).

Higher PAR readings (> 45 %) were taken under the canopies of *A. aculeata C. alliodora*, and *T. rosea* in all seasons compared to the other species. On the contrary, *E. cyclocarpum* and *G. ulmifolia* transmitted significantly ($P < 0.05$) lower PAR 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 *A. aculeata* and *C. alliodora*, around 40 % for *T. rosea* and *S. saman* and around 20% for *E. cyclocarpum* and *G. ulmifolia*.

Standing Herbage Biomass availability

Standing herbage biomass harvested underneath tree canopies was significantly ($P < 0.05$) higher under *A. aculeata*, *C. alliodora*, *S. saman* and *T. rosea* canopies than under *E. cyclocarpum* and *G. ulmifolia*. The lowest SHB availability was obtained under the *E. cyclocarpum* canopy, which was 41% lower than *G. ulmifolia* 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 tree species except for *A. aculeata* which had 12 % less DM ha^{-1} under the canopy when compared to that measured in open pasture (Table 2).

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 3; $P < 0.002$), and the species - season interaction was not significant ($P = 0.98$).

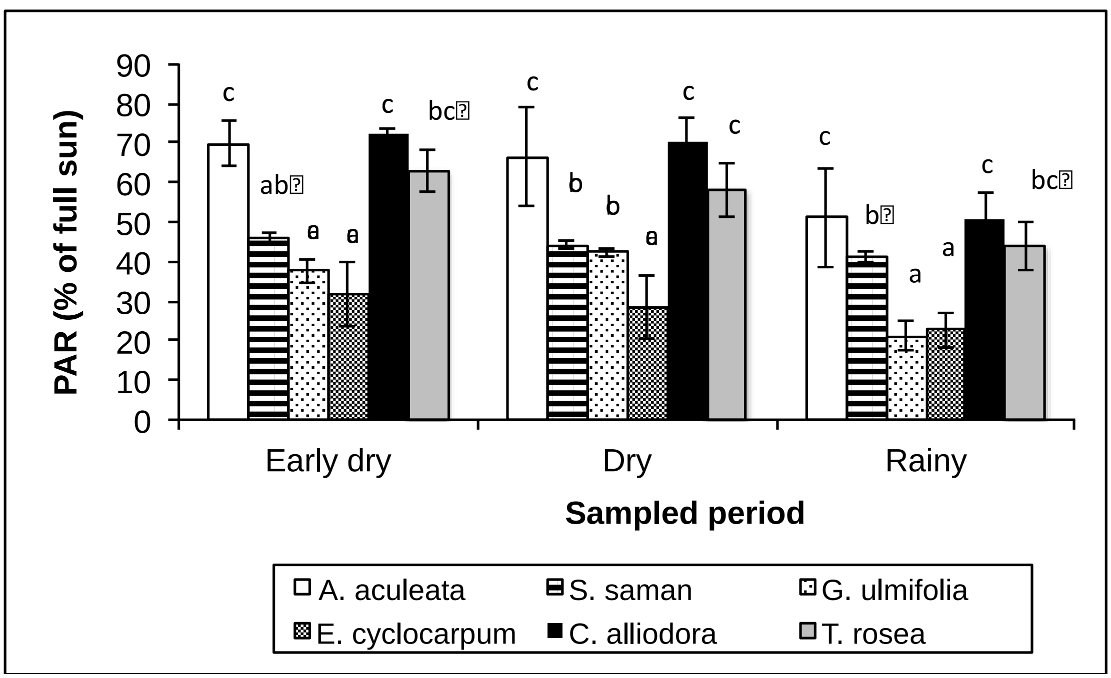

Figure 2. Photosyntetic Active Radiation (PAR) as % of full sun light underneath isolated tree crowns of six tree species isolated in *Brachiaria brizantha* paddocks in a dry tropical ecosystem in Cañas, Guanacaste Costa Rica.

Table 2. Photosynthetic active radiation (PAR) measured under tree canopies and standing herbage biomass (SHB g DM m^2) harvested in open zones and underneath isolated tree crowns of six tree species growing in *Brachiaria brizantha* paddocks in a dry tropical ecosystem in Cañas, Guanacaste Costa Rica.

			Standing Herbage Biomass in sampled zone		Sampled zone effect	
Species	Trees (n)	% PAR transmitted	Open (SE)	Shaded (SE)	Difference# (%)	P value
A. aculeata	9	60.6	562.0 (53.9) a	494.7 (65.6) b	88	0.140
C. alliodora	12	64.4	603.0 (45.8) a	440.8 (45.3) b	73	0.005
E.cyclocarpum	6	27.1	548.4 (65.6) a	132.4 (79.4) a	23	0.002
G. ulmifolia	9	33.7	597.1(58.2) a	223.7 (56.8) a	38	0.001
S. saman	3	49.4	608.3 (105.7)a	423.3 (69.2) b	70	0.080
T. rosea	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**

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. Standard errors are presented in parenthesis.

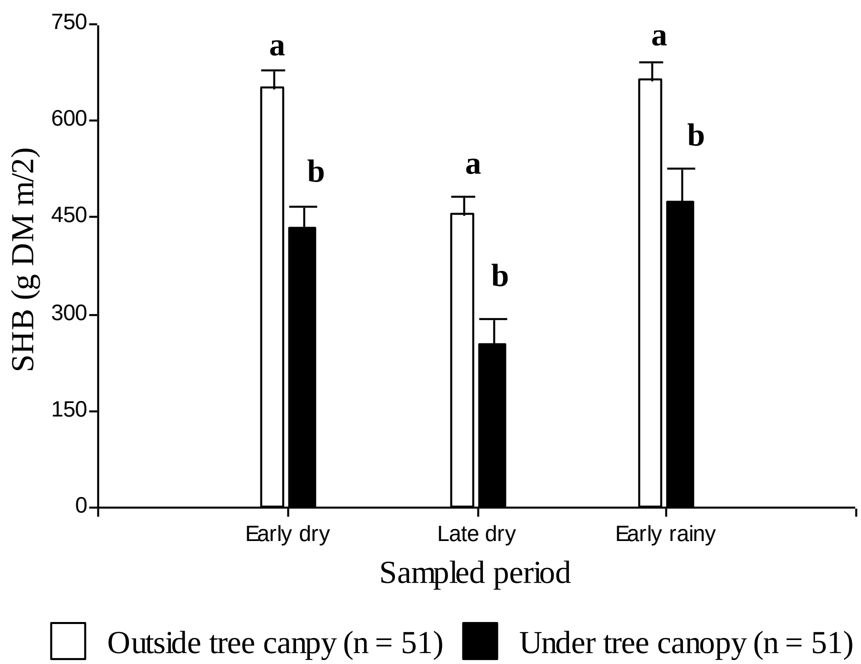

Figure 3. Standing herbage biomass (SHB g DM m^2) harvested in each season in open zones and underneath tree crowns of six tree species (n = 51 trees total) found dispersed in *Brachiaria brizantha* paddocks in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica. Bars with a different letter within a season indicate significant differences (P < 0.002) using paired "t" test.

Standing Herbage Biomass botanical composition

Pasture vegetation outside canopies of all tree species as well as under the canopies of *A. aculeata*, *C. alliodora* and *T. rosea* and 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 *Triunfetta semitriloba* weed. There was a high percentage (10 to 65) of bare soil under *G. ulmifolia* and *E. cyclocarpum* crowns which underneath vegetation was dominated by a mixture of *Richardia* spp and *Triunfetta semitriloba* weeds.

Quality of SHB

The SHB under the *E. cyclocarpum* canopies had significantly higher CP content than the other species ($P < 0.05$). Similarly, CP of SHB under the canopies of *G. ulmifolia* and *S. saman* was significantly higher than underneath *A. aculeata*, *C. alliodora*, *T. rosea* ($P < 0.05$). The CP of SHB under the canopies of all tree species was consistently higher ($P < 0.05$) than outside the canopies although highest differences were observed for *E. cyclocarpum* (128 %) and *S. saman* (67 %), which are leguminous species (Table 3).

In vitro dry matter digestibility of SHB was significantly higher ($P < 0.05$) under *S. saman* canopies than that under *E. cyclocarpum* and *G. ulmifolia* canopies. The lowest IVDMD ($P < 0.05$) was found under the canopies of *E. cyclocarpum*. *In vitro* DMD was also significantly different ($P < 0.05$) between sampling zones for all species except that of *S. saman* and *T. rosea*. The SHB under canopy of *A. aculeata* and *C. alliodora* had significantly higher IVDMD values than outside tree canopies. On the other hand, SHB under the canopies of *E. cyclocarpum* and *G. ulmifolia* had significantly lower IVDMD values compared to outside the canopy. Neutral detergent fiber (Table 3) was significantly lower ($P < 0.05$) under the canopy of *G. ulmifolia* than under canopies of the other species. When comparing NDF between sampling zones, it was significantly lower under the canopies of *E. cyclocarpum* ($P = 0.07$) and *G. ulmifolia* ($P = 0.01$) than outside the canopies.

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.

Table 3. Mean crude protein (CP %), *in vitro* dry matter digestibility (IVDMD %) and neutral detergent fiber (NDF %) of the standing herbage biomass (SHB g DM m^2) harvested in open zones and underneath tree crowns of six tree species found dispersed in *Brachiaria brizantha* paddocks in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica.

		Sampled zone		Sampled zone effect	
Species	Trees (n)	Open	Shaded	Difference# (%)	P value
			CP (%)		
A. aculeate	9	4.9 (0.6) a	6.1 (0.8) a	25.0	0.040
C. alliodora	12	4.6 (0.5) a	5.7 (0.6) a	24.0	0.004
E. cyclocarpum	6	5.3 (0.8) a	12.1 (1.3)c	128.0	0.050
G. ulmifolia	9	5.5 (0.5) a	7.7 (1.0) b	40.0	0.050
S. saman	3	4.6 (0.8) a	7.7 (1.2) b	67.0	0.050
T. rosea	12	4.6 (0.5) a	5.9 (0.5) a	28.0	0.001
Mean		4.9 (0.2)	6.7 (0.4)	37.0	0.0001
			IVDMD (%)		
A. aculeate	9	46.1 (1.5) a	47.9 (1.5) bc	4.0	0.010
C. alliodora	12	44.8 (1.4) a	47.5 (1.2) bc	6.0	0.003
E. cyclocarpum	6	45.8 (1.7) a	35.3 (3.6) a	-23.0	0.010
G. ulmifolia	9	47.1 (1.7) a	43.1 (2.1) b	-8.5	0.050
S. saman	3	49.1 (2.1) a	48.9 (1.1) c	-0.4	0.880
T. rosea	12	46.0 (1.3) a	47.5 (1.1) bc	3.0	0.160
Mean		46.1 (0.6)	46.1 (0.8)	0.0	0.890
			NDF (%)		
A. aculeate	9	79.2 (1.2) a	79.3 (1.0) b	0.1	0.89
C. alliodora	12	80.5 (0.9) a	80.0 (0.7) b	0.5	0.39
E. cyclocarpum	6	81.9 (2.7) a	74.4 (0.5) b	-8.0	0.07
G. ulmifolia	9	79.3 (0.8) a	58.6 (6.6) a	-28.0	0.01
S. saman	3	81.8 (2.1) a	78.5 (1.0) b	-4.0	0.19
T. rosea	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.

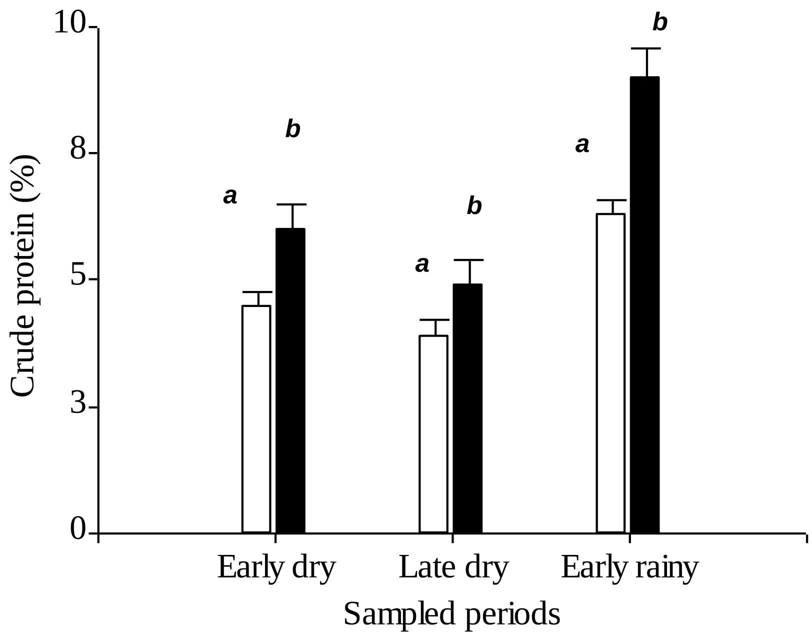

Figure 4. Crude protein percentage of standing herbage biomass at open zones and underneath tree crowns of six tree species found dispersed in *Brachiaria brizantha* paddocks in a dry tropical ecosystem in Cañas, Guanacaste, Costa Rica. Bars with a different letter within seasons indicate significant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

In vitro DMD 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 3) 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.

DISCUSSION

Higher SHB was harvested during the rainy season than the dry season. 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 (Figure 1). The study also showed that irrespective of the season, less light reaching the understory reduced the SHB dry matter availability in comparison to SHB harvested from outside the canopy (open). 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´t saturate their photosynthesis rates even at full radiation levels. However, the extent of biomass reduction observed largely depends on the interception of solar radiation caused particularly by the tree species. *Acrocomia aculeata*, *C. alliodora* and *T. rosea* species which have small tree crown areas (19.5 to 90 m^2) permit the transmission of higher PAR under their canopy in comparison to the other tree species such as *E. cyclocarpum* and *G. ulmifolia* which have lower levels of light transmission (< 30 %) which explains the SHB differences found between selected tree species . Similar findings to this study have been reported by Rozado-Lorenzo *et al* (2007) in a silvopastoral system who found lower pasture production under conifer trees than under broadleaved trees. Eriksen and Whitney (1981) also found 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 and *Acacia tortilis*, *C. alliodora* and *T. rosea* (Belsky *et al*., 1993a; Belsky *et al*., 1993b; Ribaski and Inoue, 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 had 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 grasses under light environments allocate a higher proportion of carbohydrates to maintain or increase leaf area while reducing biomass allocation to roots (Kephart *et al*., 1992; Dias-Filho, 2000). Thus, since forage re-growth depends to a large extent on the 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).

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 those experienced 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 (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 *E. cyclocarpum* was dominated just by a single broad-leaf weed species, whereas that of *G. ulmifolia* 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 *E. cyclocarpum* and *G. ulmifolia* in comparison to the other tree species.

CONCLUSION

Throughout all seasons, light reduction caused by tree canopies reduced SHB availability underneath tree canopies compared to full sun areas, but this reduction varied accordingly to tree species crown canopy architecture; larger and denser tree crown canopies, which intercept more PAR, permitted low light transmission under their crowns, reducing standing herbage biomass at higher extent than trees with open and smaller crown types. Standing herbage quality, particularly crude protein, was increased underneath tree species canopies compared to that at full sunlight regardless of tree crown canopy architecture.

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