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Sward structure and herbage intake of *Brachiaria brizantha* cv. Piatã in a crop-livestock-forestry integration area

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ABSTRACT

Forage species tolerate varying degrees of shading. In agrosilvopastoral systems, forage plants are able to adjust and partially compensate growth reduction under light stress. These adjustments change morphological proportions and composition along the vertical profile of the sward. Sward morphological composition is directly related to animal intake behavior and performance. One objective of this study was to evaluate the effects of different tree shading levels on sward vertical structure of Piatã palisadegrass cultivated in a crop-livestock-forestry integration area. Another objective was to identify the relationship between sward vertical structure and herbage intake by cattle (*Boss pp.*). Three experiments were conducted simultaneously to evaluate three shading levels: 1. Full sunlight (FS); 2. Moderate shade (MS; 338 trees.ha^{-1}); and Intense shade (IS; 714 trees.ha^{-1}). Evaluation was performed during three periods in which total rainfall during the experimental period corresponded to 86, 12 and 2% (periods 1, 2 and 3, respectively). Pastures were rotationally stocked and grazed at 95% canopy light interception (LI) during regrowth (95% LI). Two strategies for taking the reference readings of LI were tested in IS paddocks: LI reading inside (under the tree canopy) and outside (under full natural light) the experimental area. The IS had greatest forage height and proportion of stems, both pre- grazing and post-grazing. Consequently, animals under IS had decreased bite mass and intake rate, pre- and post-grazing except for period 3. There was an effect of shading level on herbage crude protein (CP) concentration. Greatest CP concentrations were observed on IS areas. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) did not vary with shading levels. Herbage dry matter digestibility varied with evaluation period, and lowest values were recorded during period 3. Greater herbage intake was observed on FS and MS relative to IS, due to greater leaf proportion in sward herbage mass. Moderate shading is not so detrimental to system's productivity, highlighting the importance of adequate choice of tree species, plant density and arrangement.

1. Introduction

Agrosilvopastoral systems are a diverse, rational, and sustainable land use alternative that aggregates value to end-products. In these systems, crop, livestock and forestry are conducted simultaneously or sequentially (Young, 1991). The presence of trees changes quality and quantity of light that reaches the forage sward, affecting animal production and productivity. Most forage species tolerate some degree of shading, mainly through phenotypical adjustments that partially compensate growth reduction (Dias-Filho, 2000). However, shade tolerance depends on shade intensity and varies across forage species (Carvalho et al., 1995), indicating that viability of crop-livestock-forage integrated (CLFI) systems is dependent of tree species and arrangement and shade tolerance of forage plants growing underneath them.

Forage plants cultivated under restricted light change their morphology as a means of avoiding shade and optimizing light interception through changes in leaf area arrangement and distribution along the vertical profile of the sward (Gomide et al., 2007; Lambers et al., 1998). The main morphological changes under shade are increased shoot-to-root ratio, specific leaf area, elongation of stem, petiole and internode, decreased ramifications, tillering, and number of leaves per tiller, and decrease in the leaf-to-stem ratio and foliage angle (Paciullo et al., 2008; Martuscello et al., 2009; Paciullo et al., 2011). Sward structure and grazing activities are directly related (Peri et al., 2001; Carvalho

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et al., 2009; Fonseca et al., 2012) and any morphological changes in sward structure affect the animals' intake behavior. Internode elongation is the most common response of forage plants under light restriction and excessive stem elongation changes animal behavior and grazing pattern (Carvalho et al., 2009), reducing intake (Peri et al., 2001; Benvenutti et al., 2009). Additionally, herbage bulk density, leaf-to-stem ratio, sward height, tiller population density and morphological composition of herbage mass interfere on time spent grazing, highlighting the importance of sward structure as determinant of daily nutrient intake (Carvalho et al., 2001; Sollenberger and Burns, 2001).

In CLFI systems, little is known about the relationships between sward morphological changes caused by shading and grazing behavior. Identification of sward structures that favor high herbage intake can improve animal productivity. The first objective of this study was to evaluate the effect of different shading levels on sward vertical structure of Piatã palisadegrass grown in a CLFI area. A second objective was to describe the effects of changes in sward structure caused by shading on short-term herbage intake by grazing cattle.

2. Material and methods

2.1. Study area

The study was conducted in Sinop, state of Mato Grosso, Brazil (11°51′ S, 55°35′ W, 384 m a.s.l.) at Embrapa Agrossilvipastoril Research Center. The experimental area comprised 10 ha of flat contour land on a Typic Hapludox, clay, caulinitic, isothermic soil (SOIL TAXONOMY, 1999). Average soil chemical characteristics (0–20 cm) were: pH (water) = 5.8; organic matter (OM) = 29.5 g dm^{-3}; $P_{(Mehlich\ )}$. = 14.3 mg dm^{-3}; $K_{(Mehlich)}$ = 71.5 mg dm^{-3}; Ca = 2.5 cmol$_c$ dm^{-3}; Mg = 0.7 cmol$_c$ dm^{-3}; Al = 0.2 cmol$_c$ dm^{-3}; Sum of bases = 3.3 cmol$_c$ dm^{-3}; base saturation = 51%. The proportions of clay, silt and sand were 594, 123 and 283 g kg^{-1}, respectively. According to Köppen classification, the climate of the region is a tropical humid or sub-humid Am type, with average annual temperature of 25 °C, air relative humidity of 76%, and annual precipitation of 2020 mm (Instituto Nacional de Meteorologia, INMET). Weather data for the experimental period (Fig. 1) were recorded at the Embrapa Agrossilvipastoril weather station and compared to historical data (last 30 years) recorded by INMET (National Institute of Meteorology).

Eucalyptus (*Eucalyptus urophilla* x *Eucalyptus grandis* clone H13) was planted in 2010 along the East-West direction in order to generate three shade regimes. The first shade regime (full sunlight, FS) was absent of trees. In the second shade regime (moderate shade, MS) trees were planted in double rows at the borders (2 m between trees in rows and 3 m between rows; 338 trees ha^{-1}; leaving 83% of the total area available for cropping/pasture in the center). In the third shade regime (intense shade, IS) trees were planted in triple rows spaced 15 m from each other (4 ranks with 2 m between trees in rows and 3 m between rows; 714 trees/ha; leaving 58% of the total area available for cropping/pasture). All shade regimes had the same cropping/pasture area, justifying the differences in total width (same length) among the areas (49, 59 and 84 m for FS, MS and IS, respectively; Fig. 2). During the first two years after eucalyptus establishment, the area between tree ranks was cultivated with maize. In January 2012, *Brachiaria brizantha* (Hochst. ex A. Rich.) cv Piatã was seeded together with maize. The maize was harvested in April, leaving the pasture available for use. Prior to the start of the experiment, pastures were adapted to the grazing strategy from November 2012 to November 2013 in order to warrant the sward structures for each shade regime. At the beginning of the experiment, in December 2013, the trees had an average height of 16 m.

2.2. Treatment layout and management of experimental conditions

The experimental period was from December 2013 to June 2014. The total area in-between ranks available for cropping/pasture was similar for all treatments. However, the layout was different for each shade treatment due to the arrangement of trees. In MS and IS, the immediate 1.5 m from each side of the tree rows was not used. Therefore, total width for FS, MS and IS was 49, 59 and 84 m, respectively, but the available width for cropping/pasture was 49 m for all shade regimes (Fig. 2). Urea was applied at 100 kg N/ha, divided into three applications (December 2013, January and March 2014). Grazing animals were crossbred Holstein x Gir dairy heifers with average body weight of 465 ± 10 kg.

In all shade regimes, pre-grazing target was 95% canopy light interception (LI) during regrowth and post-grazing stubble height was set to 50% of the pre-grazing height (Carvalho et al., 2009; Fonseca et al., 2012). Under trees, different from a pasture only system, interception of the incident light may be measured in two ways: (1) considering the combined canopies of trees and forage plants, and (2) considering only the forage plants canopy after light has passed through the tree canopy. This may result in different light environments (quantity and quality) for the same target of 95% LI. For that reason, two strategies to monitor canopy LI were evaluated. The first used readings of the incident light above the sward canopy as a reference of canopy LI (under the tree canopy; referred to hereon in as "inside"). The second used readings of the incident light taken above the tree canopy (referred to hereon in as "outside"). In this case, readings were taken in an adjacent field with no trees, and were performed only for IS (Fig. 2), since this was the condition that could generate the largest differences between strategies if

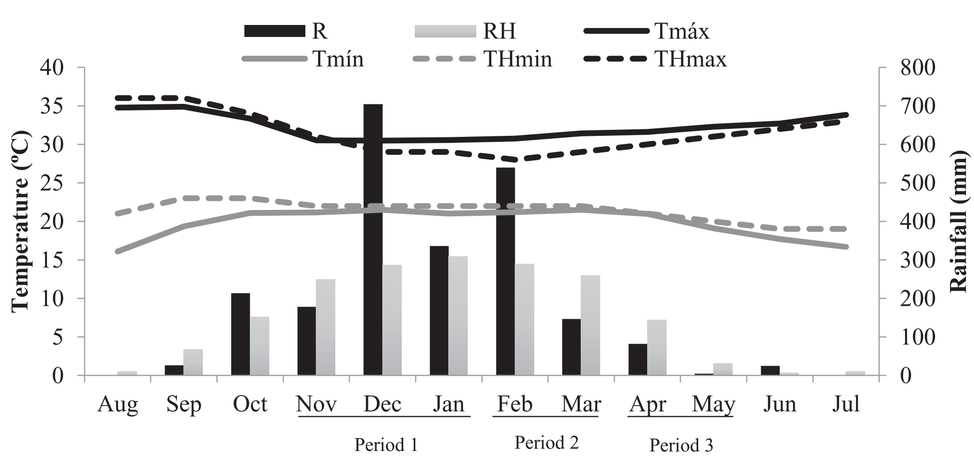

Fig. 1. Rainfall (R) and maximum (Tmax) and minimum (Tmin) air temperature from August 2013 to June 2014 and historical records of Rainfall (RH) and maximum (THmax) and minimum air temperature (THmin) from 1985 to 2015, for Sinop, MT, Brazil.

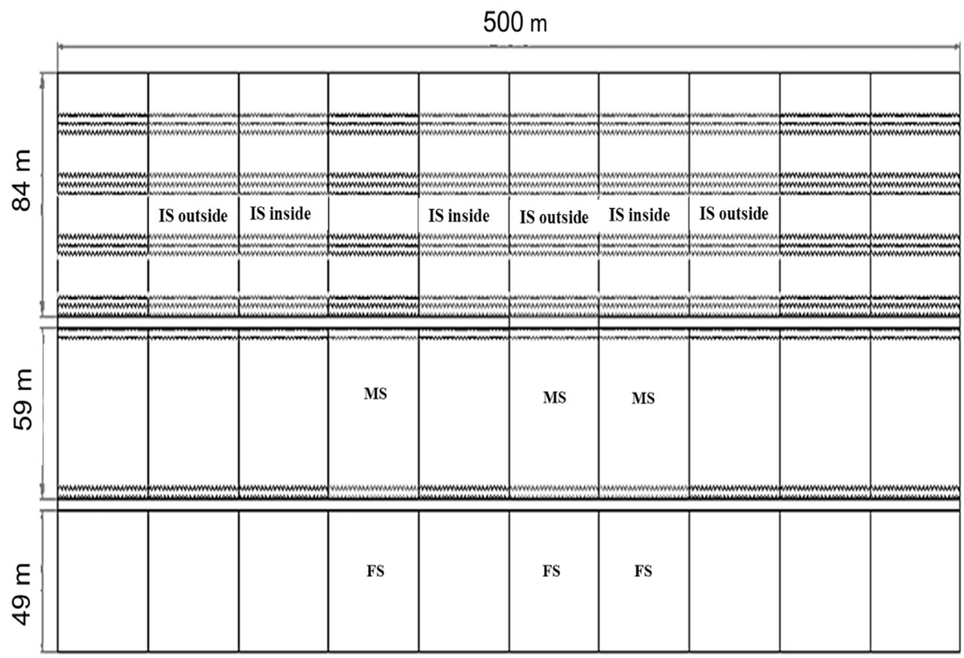

Fig. 2. Layout of the experimental area showing the sampling paddocks for the three shade regimes (FS, MS and IS) and the two methods for monitoring canopy light interception (inside and outside).

there were any. Three paddocks from each shade regime were used as sampling units (replicates; total of 12 sampling paddocks, three for FS, MS and IS-inside and other three for IS-outside).

In order to take into account the impact of tree distance on pasture light distribution, sampling paddocks for MS and IS were stratified into three sampling strips: two lateral strips (closer to the tree rows) and one central strip (in-between the two lateral strips). For MS, the two lateral strips had 4 m each (not considering the 1.5 m tree borders), and the central strip had 41 m. In the ISS regime, the total 49 m width area designated for cropping/pasture was divided in four sub-paddocks (three 12 m wide and one 13 m wide; Fig. 2). Samples were taken in the central sub-paddock (12 m wide), and lateral and central strips had 4 m each.

2.3. Measurements

The experimental period was divided into three evaluation periods based on rainfall distribution (Fig. 1): (1) Period 1 = December 2013, January and February 2014; (2) Period 2 = March and April 2014; and (3) Period 3 = May and June 2014. Rainfall distribution was 86, 12 and 2% of the total rainfall during periods 1, 2 and 3, respectively. Data were collected until June 2014, when rates of herbage accumulation became too small and did not allow swards to reach the 95% LI pre-grazing target.

2.3.1. Light environment

Photosynthetic active radiation (PAR) was measured in automatic weather stations equipped with Model PQS 1 PAR Quantum Sensors (Kipp & Zonen, USA Inc.). These were set to take readings at 5-second intervals (averaging values every 15 minutes and every hour) and to provide daily estimates. These data were used to continuously evaluate the different conditions of radiation flux density. In FS the weather station was placed in the center of the cropping/pasture area. In MS, there were 4 weather stations, located underneath the trees, at the center of the cropping/pasture area, and closer to the tree rows at the border of the cropping/pasture area (2 stations). In IS, there were four stations located underneath the second triple row of trees and at the cropping/pasture area equally spaced from each other (3 stations). Additionally, one station was positioned in an open, flat grass field approximately 500 m from the experimental area, as a control. Data from the weather stations were used to characterize the shade strips of each shade regime (weighted means calculated per experimental unit using their width as weighting factor).

2.3.2. Canopy light interception

Canopy light interception was measured at pre-grazing and post-grazing using a LI-2200 canopy analyzer (LI-COR, Lincoln, NE, USA) from 5:30 to 7:30 am. The number of readings per paddock varied with the width of the shade strips. Readings were randomly taken above the sward canopy (when measurement of the incident light was made within the experimental area – inside strategy) and at the soil level (ratio of 1:10 readings), along a "W" shape line used to guide and maintain consistency of sampling. In FS, 40 readings were taken in the central portion of each paddock. In MS, 40 readings were taken at the central and lateral strips (80 readings total). In IS, 20 readings were taken at the central strip and 40 at the lateral strip (60 readings total). The LI-2200 measurement bar was positioned at the midpoint between tussocks for the soil level readings. The average value of sward canopy LI and foliage angle was calculated as weighted mean using as reference the width of the shade strips.

2.3.3. Sward height

Measurements of sward height were taken with a sward stick (Barthram, 1985). Sampling followed the same procedure described for monitoring canopy light interception. Readings corresponded to canopy height in a 20 to 30 cm radius in relation to the stick. Sward height was monitored during grazing to maintain the established post-grazing target (as close as possible to 50% of the pre-grazing height).

2.3.4. Herbage mass

Herbage mass was evaluated at pre-grazing and post-grazing using 0.25 m^2 (0.35 × 0.71 m) frames. Two samples were harvested (at 3 cm from soil level) from each shade strip in areas representative of sward conditions at the time of sampling (visual assessment of height and herbage mass). Two samples were collected from FS and 6 samples were collected from MS and IS (2 samples in the central and each lateral strips). Harvested samples were dried at 65 °C until constant weight, and herbage mass values are expressed on a DM basis.

2.3.5. Vertical structure of the sward

The vertical distribution of sward morphological components was monitored using the inclined point quadrat method (Warren Wilson, 1960), at pre-grazing and post-grazing. The inclination used was 32.5^0 degrees. The inclined point quadrat was positioned in areas representative of sward condition at the time of sampling (visual assessment of height and herbage mass). Morphological components were identified as leaf, stem (stems + sheaths), dead material and weeds (any plant other than Piatã grass). Components were identified and their height relative to ground level was determined. Because of differences in sward herbage mass and height among sampling paddocks, the total number of points monitored was different among treatments, but a minimum of 100 points per paddock were monitored.

2.3.6. Intake rate

Bite rate and bite mass were estimated at the beginning and at the end of each grazing using two esophageal cannulated crossbred Holstein × Gir dairy heifers (average body weight 450 ± 35 kg). The heifers were fastened for 6 hours prior to sampling to avoid contamination of extrusa with ruminating material, and to ensure that animals would actively graze the sampling paddocks. Heifer grazing behavior was monitored during 15-minute shifts by two trained observers, who monitored the time spent by each animal to take 20 bites. Data were used to calculate bite rate (n^o bites min^{-1}) according to Hodgson (1982) and the values are expressed on a dry matter basis (DM). The total number of bites taken was calculated as the product between bite rate and shift duration. Bite mass (BM, g DM bite^{-1}) was calculated by the following equation: BM = (g feed consumed) / (n^o bites min^{-1} × shift duration). Intake rate (g min^{-1}) was calculated by the product between bite mass (g DM bite^{-1}) and bite rate (n^o bites min^{-1}). All measurements regarding animal responses were taken according to the Institutional Animal Care and Use Guidelines of EMBRAPA (Protocol 001/2015).

2.3.7. Morphological composition of the consumed herbage

Extrusa samples were weighed and divided into two sub-samples. One sub-sample was oven dried at 55 °C to constant weight for dry matter determination. The second sub-sample was stored at −18 °C until morphological composition determination. These samples were later thawed and used for morphological composition assessment. The samples were cleaned with running water, to remove saliva contamination (Trindade et al., 2007), and homogenized. The fragments were distributed on a measuring glass tray, marked with 1 cm^2 grid, and evenly distributed with the aid of water (approximately 100 mL). The fragments of 100 randomly selected grid points were collected and stored. An optical magnifying glass was used for identification of the components from each point: leaf, stem (stems + sheaths) and dead material. The proportion of each component was then calculated.

2.3.8. Herbage chemical composition

Herbage samples were collected randomly, at pre-grazing, for chemical composition evaluation. Samples were composed of the herbage available above the post-grazing height of the previous grazing cycle. Samples were oven dried at 55 °C until constant weight and ground to 1 mm. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were determined following the method of Van Soest et al. (1991). *In vitro* dry matter digestibility (IVDMD) was quantified by fermentation with an ANKOM® Technology Corporation DAISY^{II} equipment (Mabjeesh et al., 2000). Total nitrogen concentration was measured by dry combustion, with a LECO FP 528 (LECO CORPORATION, St. JOSEPH, MI, USA). Crude protein was determined by multiplying total nitrogen by 6.25.

2.4. Statistical analyses

Data were analyzed using the combined experiments technique (Moore and Dixon 2015), in which each shade regime was considered as an independent experiment. As a result, the number of replications corresponded to the number of sampling paddocks (n = 3) and the sources of variation were: shade regime (FS, MS and IS); strategy for monitoring canopy light interception (inside and outside); and evaluation period (1, 2 and 3). Each source of variation was studied by combining experiments with similar characteristics. For instance, the strategy for monitoring canopy light interception, a variation of LI measurements carried out in IS, was analyzed using data from IS only.

Within experiments data were analyzed using the Mixed Procedure of SAS® (SAS Inst., Cary, NC, USA), with repeated measures and using the restricted maximum likelihood (REML) method. The experimental error and paddocks (experimental units) were considered random effects and all the remaining sources of variation causes and their interactions considered fixed effects. The number of grazing cycles and grazing intervals as well as the data from the inclined point quadrat measurements were not subjected to analysis of variance, and only descriptive statistics were used to present them.

The statistical model used was:

$$y_{iklm} = \mu + S_i + M_{(i)k} + \omega_{(ik)m} + P_{(ik)l} + MP_{(ik)l} + \varepsilon_{(ikl)m}$$

Where y_{ijklm} is the response variable; μ, S_i, and $M_{(i)k}$ are the fixed effects associated with the mean, shade regime (i = 1, 2, 3), and method for monitoring canopy light interception (k = 1, 2), respectively; $\omega_{(ik)m}$ is the random effect associated with sampling paddocks (replications) - $\omega_{(ik)m} \sim N(0;\sigma_w^2)$; $P_{(ik)l}$, and $MP_{(ik)l}$ are the fixed effects associated with evaluation period (l = 1, 2, 3) and strategy for monitoring canopy light interception × evaluation period interactions, respectively; ε_{iklm} is the random effect associated with the experimental error, $\varepsilon_{iklm} \sim NID(0;\sigma_e^2)$.

Data from the three isolated experiments were tested for heteroscedasticity of variances. When variances were heterogeneous, they were considered independently, but were grouped as homogeneous whenever possible. The correlation/covariance matrix was chosen using the Schwarz's Bayesian Criterion (SBC or BIC in SAS) (Littell et al., 2000), and the correction for degrees of freedom made using the Kenward and Rogers (1997) method (SAS command: DDFM = KR). Treatment means were calculated using the 'LSMEANS' statement and comparisons made using the Student test at $P < 0.05$.

3. Results

3.1. Sward height and canopy light interception

The tree arrangements used to create MS and IS resulted in 18.1 and 55% reduction in PAR in the cropping/pasture area relative to FS, respectively (Table 1).

The 95% LI target was met in all shade regimes throughout the experiment. Increased shade level resulted in increased pre-grazing

Table 1
Average daily transmittance of photosynthetic active radiation on *Brachiaria brizantha* cv. Piatã under shade regimes and rotational grazing management in CLFI systems from December 2013 to July 2014.

Shade regime	Evaluation period			Mean
	1	2	3	
(%)				
FS	100	100	100	100
MS	83.1	82.8	79.9	81.9
IS	47.0	49.2	38.8	45.0

[1]Transmittance = PAR of shade regime/PAR of full sunlight regime.

Table 2
Structural characteristics of *Brachiaria brizantha* cv. Piatã under shade regimes and rotational grazing management in CLFI systems from December 2013 to July 2014.

Evaluation period	Shade regime	LI Pre-grazing (%)	LI Post-grazing (%)	Pre-grazing height (cm)	Post-grazing height (cm)	Post-grazing herbage mass (kg DM ha^{-1})	Pre-grazing herbage mass (kg DM ha^{-1})	Grazing interval (Days)
1	FS	95.5 (0.42)	82.7 (0.35)	34.9 (1.95)	20.4 (0.24)	3450 (187)	5300 (313)	20.4 (0.10)
	MS	95.2 (0.20)	82.6 (1.01)	37.6 (0.48)	20.2 (0.78)	2900 (102)	4700 (208)	27.4 (0.30)
	IS outside	95.3 (0.20)	87.9 (0.32)	44.6 (0.51)	26.9 (2.19)	1200 (226)	2800 (103)	25.9 (0.20)
	IS inside	94.6 (0.12)	79.4 (1.55)	54.5 (1.96)	29.1 (1.96)	2200 (357)	3100 (107)	35.0 (2.00)
2	FS	95.7 (0.06)	84.6 (0.91)	33.6 (0.68)	21.5 (0.68)	3310 (187)	5300 (287)	20.5 (1.6)
	MS	95.5 (0.28)	81.1 (1.83)	33.9 (1.47)	20.8 (0.50)	2900 (195)	4100 (308)	25.5 (0.30)
	IS outside	95.8 (0.10)	89.6 (0.79)	40.7 (0.61)	24.3 (0.68)	1900 (131)	3000 (249)	26.7 (0.30)
	IS inside	95.3 (0.45)	80.2 (1.58)	50.5 (3.70)	26.2 (3.04)	2200 (179)	3500 (213)	35.7 (2.18)
3	FS	94.8 (0.18)	77.2 (3.20)	30.1 (1.33)	23.3 (3.48)	3400 (321)	5600 (621)	32.5 (0.57)
	MS	95.1 (0.32)	79.8 (1.85)	32.7 (1.62)	19.8 (1.01)	3200 (609)	4600 (157)	33.3 (1.20)
	IS outside	95.1 (0.49)	84.6 (2.75)	43.4 (0.74)	22.8 (0.98)	1900 (366)	2700 (276)	33.3 (1.45)
	IS inside	94.4 (0.12)	72.8 (1.55)	50.4 (1.96)	27.0 (0.24)	1800 (335)	3150 (113)	39.17 (2.10)

Values within brackets are standard error of the mean. "Outside" = reference reading for light interception values taken outside the experimental areas (without trees). "Inside" = reference reading for light interception values taken inside the experimental areas (under the trees).

sward height, and reduced pre-grazing and post-grazing herbage mass. Grazing interval increased with shade level, therefore IS inside had the longest grazing interval. Post-grazing height was kept close to the target, remaining under 50% of the pre-grazing height throughout the experiment for all treatments (Table 2).

3.2. Sward vertical structure

At pre-grazing, sward height was less for FS and MS relative to IS. Regardless of shade treatment, the upper half of the sward was composed mainly by leaves. Leaf proportion decreased, and stem and dead material proportion increased in the lower half. During period 3 the proportion of dead material increased in the upper half of the sward, relative to periods 1 and 2 (Figs. 3, 4 and 5). In relation to the strategies for monitoring canopy LI, greater sward height was measured for the "inside" relative to the "outside" strategy, condition that was also associated with greater proportion of stem in the top half of the sward. The same pattern was observed at post-grazing (Figs. 3, 4 and 5).

3.3. Herbage intake

3.3.1. Intake behavior

At the beginning of grazing, intake rate varied with shade regime ($P = 0.0013$), evaluation period ($P < 0.0001$) and shade regime × evaluation period interaction ($P = 0.0043$). Intake rate decreased during period 3 (Table 3). During periods 1 and 2, lower intake rate was observed for IS relative to FS and MS. There was no difference between shade regimes during period 3. Bite mass varied with shade regime ($P = 0.0329$), evaluation period ($P < 0.0001$) and shade regime × evaluation period interaction ($P = 0.0012$), and decreased from period 1 to 3. Bite mass was greater in FS and MS relative to IS during periods 1 and 2. Bite rate varied with the shade regime × evaluation period interaction ($P = 0.0338$). Bite rate was lower for FS and MS during period 2 (Table 3).

At the end of grazing, intake rate varied with shade regime ($P = 0.0353$), evaluation period ($P = 0.0026$) and shade regime x evaluation period interaction ($P = 0.0327$). Intake rate decreased from period 1 to 3. During period 1, intake rate was lower for IS relative to FS and MS. However, during period 2 there was no difference in intake rate between MS and IS. During period 3, intake in FS was less than in

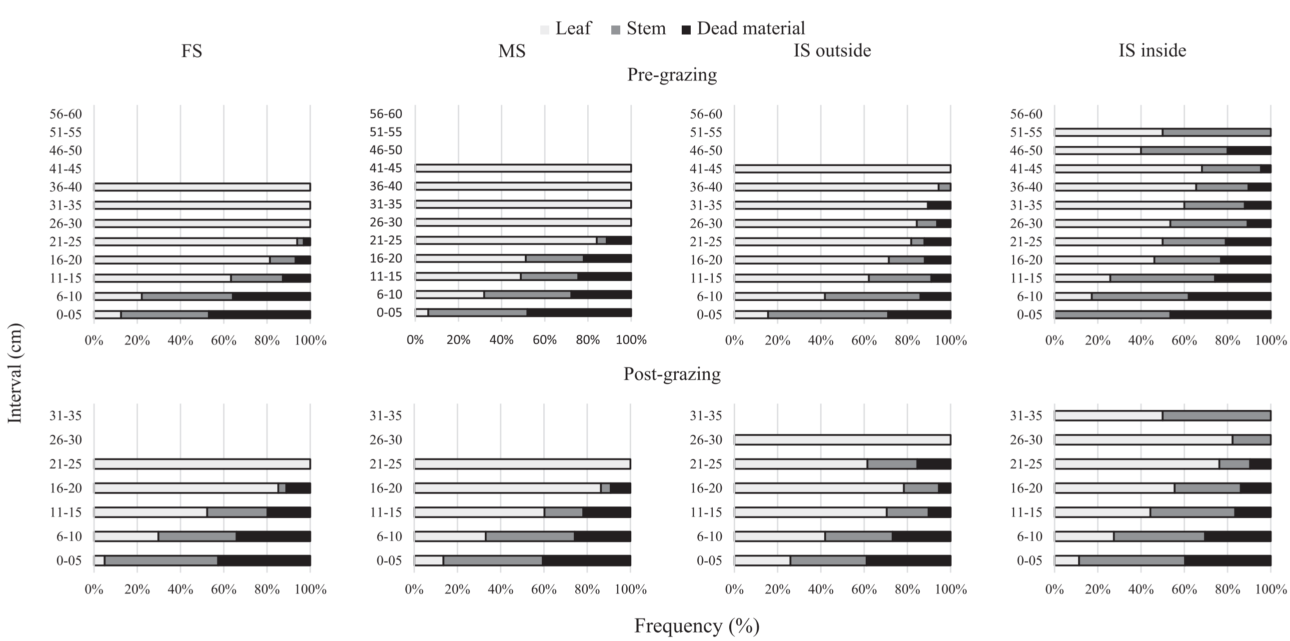

Fig. 3. Vertical Sward structure during the evaluation period 1.

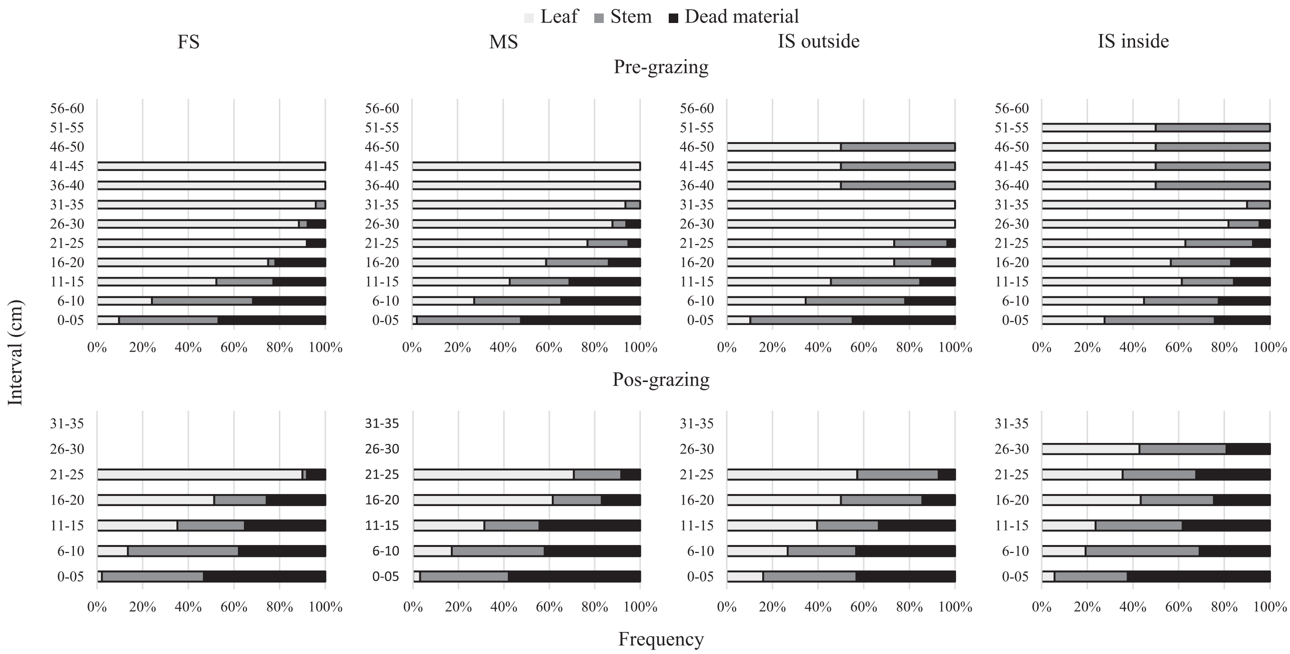

Fig. 4. Vertical Sward structure during the evaluation period 2.

MS and IS (Table 3). Bite mass varied with shade regime ($P < 0.0001$), strategy for monitoring LI ($P = 0.0035$), evaluation period ($P < 0.0001$), and shade regime × evaluation period interaction ($P < 0.0001$). Bite mass decreased from period 1 to 3. During periods 1 and 2, bite mass was less for IS relative to FS and MS. However, during period 3, bite mass was greater for MS relative to FS and IS. Bite mass was less for "inside" (0.79 ± 0.01) relative to "outside" (0.83 ± 0.01) paddocks. Bite rate varied only with evaluation period ($P = 0.0230$), with greater values measured in period 1 relative to periods 2 and 3 (Table 3).

3.3.2. Morphological composition of the consumed herbage

At the beginning of grazing, the percentage of leaf in the extrusa varied with evaluation period ($P = 0.0003$) and shade regime × evaluation period interaction ($P = 0.0057$). Leaf percentage decreased from period 1 to 3. During period 1, leaf percentage was greatest for FS. During period 2, there was no difference among shade regimes, and during period 3 values were greater for IS relative to FS (Table 4). Stem percentage varied with evaluation period ($P < 0.0001$) and shade regime × evaluation period interaction ($P = 0.0006$). Stem percentage increased from period 1 to 3. During period 1, stem percentage was greater for IS relative to FS and MS. During period 2, there was no difference among shade regimes and during period 3 values were greater for FS relative to MS and IS. Dead material percentage varied with shade regime ($P = 0.0009$), evaluation period ($P < 0.0001$) and shade regime × evaluation period interaction ($P = 0.0005$). Values increased from period 1 to 3. During period 1, dead material percentage was greatest for IS, but no differences were observed during period 2.

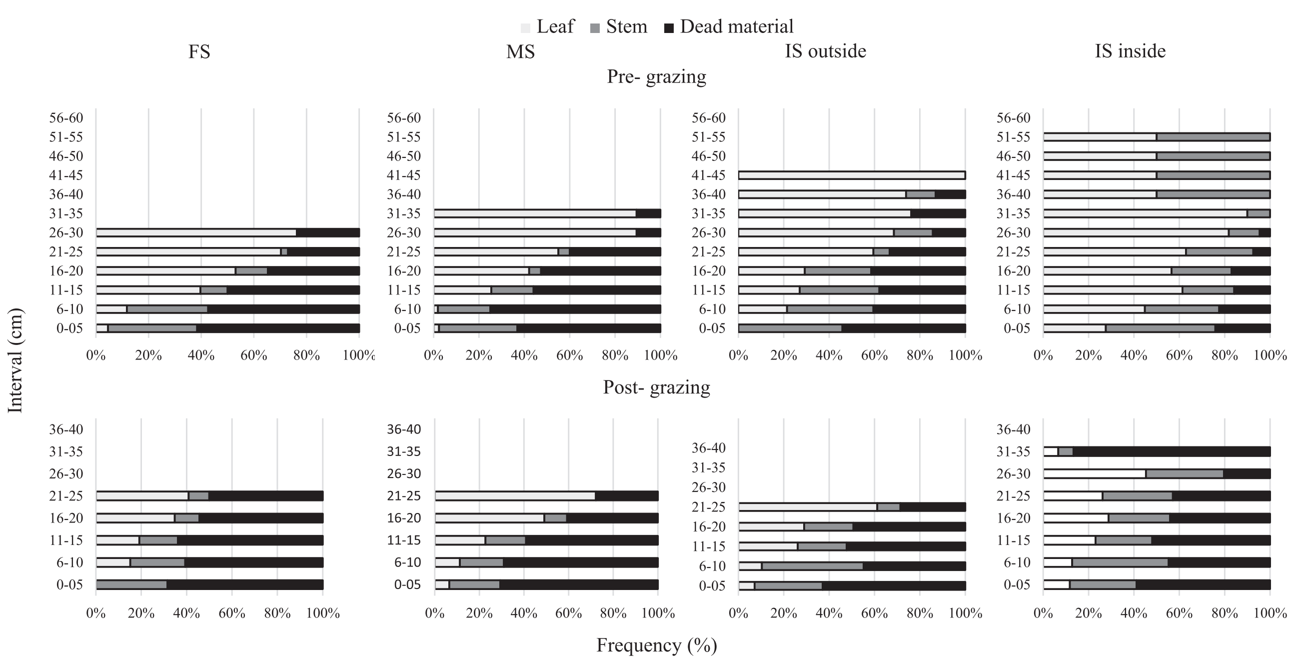

Fig. 5. Vertical Sward structure during the evaluation period 3.

Table 3
Intake rate (g DM min^{-1}), bite mass (g DM bite^{-1}) and bite rate (bite DM min^{-1}) at the beginning and end of grazing of *Brachiaria brizantha* cv. Piatã under shade regimes and rotational grazing management in CLFI systems from December 2013 to July 2014.

Evaluation period	Bite rate				Bite mass				Intake rate			
	Shade regime				Shade regime				Shade regime			
	FS	MS	IS	Mean	FS	MS	IS	Mean	FS	MS	IS	Mean
					Beginning of grazing							
1	44.9Aa (1.55)	41.0Aa (1.55)	43.7Aa (1.10)	43.6 (0.41)	1.20Aa (0.02)	1.20Aa (0.02)	0.90Ab (0.02)	1.10A (0.02)	53.6Aa (1.31)	49.2Ba (1.31)	42.7Bb (0.92)	48.4A (0.71)
2	42.8Ab (0.79)	42.6Ab (0.79)	45.6Aa (0.56)	43.6 (0.41)	1.20Aa (0.02)	1.20Aa (0.01)	1.00Ab (0.01)	1.10A (0.02)	52.6Aa (1.28)	50.9Aa (1.28)	46.1Ab (0.91)	49.8A (0.71)
3	43.9Aa (0.56)	43.8Aa (0.56)	43.1Aa (0.39)	43.2 (0.29)	1.00Ba (0.03)	1.00Ba (0.03)	0.90Aa (0.02)	1.00B (0.01)	44.3Ba (1.45)	45.9Ba (1.45)	42.7Ba (1.03)	44.3B (0.71)
Mean	43.6 (0.69)	42.4 (0.69)	44.1 (0.49)		1.10a (0.02)	1.10a (0.02)	0.90b (0.01)		50.1a (0.89)	47.4a (0.89)	43.8 b (0.63)	
					End of grazing							
1	39.0 (1.56)	38.9 (1.56)	41.82 (1.10)	39.9A (0.82)	1.02Aa (0.01)	0.98Ba (0.01)	0.81Ab (0.01)	0.94A (0.09)	40.1Aa (1.36)	38.2Aa (1.36)	34.0Ab (0.96)	37.5A (0.71)
2	37.6 (1.56)	34.36 (1.56)	40.2 (1.10)	37.4B (0.82)	1.01Aa (0.01)	1.04Aa (0.01)	0.83Ab (0.01)	0.96A (0.09)	38.3Aa (1.36)	35.7ABab (1.36)	33.4Ab (0.96)	35.8A (0.71)
3	36.7 (1.82)	37.65 (1.82)	39.7 (1.10)	38.0B (0.30)	0.72Bc (0.01)	0.88Ca (0.02)	0.79Ab (0.01)	0.80B (0.01)	27.4Bb (1.64)	33.2Ba (1.64)	31.6Aa (0.96)	30.4B (0.83)
Mean	37.8 (1.27)	36.9 (1.27)	40.56 (0.87)		0.92b (0.01)	0.96a (0.01)	0.81c (0.07)		35.0a (1.00)	35.7a (1.00)	33.0b (0.67)	

Means followed by the same small letter in lines and same capital letter in columns do not differ ($P > 0.05$). Values within brackets are the standard error of the mean.

Table 4
Morphological composition of the consumed herbage at the beginning and end of grazing on *Brachiaria brizantha* cv. Piatã under shade regimes and rotational grazing management in CLFI systems from December 2013 and July 2014.

Evaluation period	% Leaf				% Stem				% Dead material			
	Shade regime				Shade regime				Shade regime			
	FS	MS	IS	Mean	FS	MS	IS	Mean	FS	MS	IS	Mean
					Beginning of grazing							
1	96.3Aa (0.39)	94.3Ab (0.39)	89.1Ac (0.77)	93.2A (0.31)	3.5Bb (0.91)	5.5Bb (0.91)	10.0Aa (0.64)	6.3B (0.48)	0.2Bb (0.2)	0.2Bb (0.20)	0.9Aa (0.14)	0.4A (0.10)
2	91.3Ba (1.55)	90.6Aa (1.55)	89.4Aa (0.69)	90.5A (0.76)	7.2Ba (1.21)	8.3Ba (1.21)	9.6Aa (0.86)	8.4B (0.64)	1.5Ba (0.55)	1.00Ba (0.55)	1.0Aa (0.39)	1.2B (0.29)
3	68.3Cb (4.26)	72.8Bab (4.26)	87.3Aa (1.47)	76.2B (2.06)	22.0Aa (2.31)	20.0Aa (2.31)	11.7Ab (1.63)	17.8A (1.21)	9.5Aa (1.11)	7.83Aa (1.14)	1.0Ab (0.78)	6.1C (0.58)
Mean	85.3 (1.53)	85.94 (4.53)	88.6 (0.50)		10.9 (0.78)	11.3 (0.78)	10.4 (0.55)		3.72a (0.43)	3.00a (0.43)	0.97b (0.30)	
					End of grazing							
1	52.0Aa (2.03)	59.0Aa 92.03)	50.4Ab (1.43)	57.1A (1.07)	33.0 (2.17)	36.2 (2.17)	42.7 (1.47)	37.3 (1.12)	5.0Ba (1.22)	4.8Ba (1.22)	6.8Ba (0.86)	5.5B (0.64)
2	62.7Aa (2.03)	54.0Bb (2.03)	48.6Ac (1.43)	55.0A (1.07)	33.3 (2.17)	38.2 (2.17)	42.6 (1.47)	38.0 (1.12)	4.0Bb (1.50)	7.8Ba (1.22)	8.7Ba (0.86)	6.9B (0.64)
3	45.1Ba (2.42)	42.4Ca (2.42)	47.8Aa (1.43)	45.0B (1.23)	31.6 (2.61)	31.9 (2.61)	41.1 (1.47)	34.8 (1.32)	23.5Aa (1.50)	25.2Aa (1.50)	11.1Ab (0.86)	19.9A (0.76)
Mean	56.9a (1.56)	51.8ab (1.56)	48.9b (1.05)		32.6b (1.59)	35.4b (1.59)	42.2a (1.59)		10.8a (0.76)	12.6a (0.76)	8.9b (0.50)	

Means followed by the same small letter in lines and same capital letter in columns do not differ ($P > 0.05$). Values within brackets are the standard error of the mean.

During period 3, values were greater for FS and MS, relative to IS.

At the end of grazing, leaf percentage in the extrusa varied with shade regime ($P = 0.0109$), evaluation period ($P < 0.0001$) and shade regime × evaluation period interaction ($P = 0.0005$). Values decreased from period 1 to 3. During periods 1 and 2, leaf percentage was greatest for FS, but in period 3 there was no difference among shade regimes (Table 4). Stem percentage varied with shade regime ($P = 0.0043$), and values were greater for IS relative to FS and MS. Dead material percentage varied with shade regime ($P = 0.0015$), evaluation period ($P < 0.0001$) and shade regime × evaluation period interaction ($P < 0.0001$). The percentage of dead material increased from period 1 to 3, however, during period 1, there was no difference among shade regimes. During period 2, values were greater for MS and IS relative to FS. During period 3, values were greater for FS and MS relative to IS (Table 4).

3.3.3. *Chemical composition of the consumed herbage*

The percentage of crude protein (CP) varied with shade regime ($P = 0.0061$), evaluation period ($P = 0.0001$) and shade regime × evaluation period interaction ($P = 0.0002$). Crude protein concentration decreased from period 1 to period 3. During period 1 and 3, CP was greatest for IS, but in period 2 there was no difference among shade regimes (Table 5). The NDF and ADF concentration did not respond to treatment variables. *In vitro* dry matter digestibility varied

Table 5
Chemical composition of the consumed herbage of *Brachiaria brizantha* cv. Piatã under shade regime and rotational grazing management in CLFI systems from December 2013 to July 2014.

CP (%)					IVDMD (%)			
Evaluation period	Shade regime				Shade regime			
	FS	MS	IS	Mean	FS	MS	IS	Mean
1	8.9Ab (0.51)	10.4Aab (0.51)	11.1Ba (0.40)	10.1A (0.27)	74.7 (2.18)	75.3 (2.18)	75.0 (1.54)	75.0a (1.15)
2	9.6Aa (1.61)	11.1Aa (1.61)	10.7Ba (0.77)	10.5A (0.80)	75.6 (2.18)	75.8 (2.18)	75.9 (1.54)	75.8a (1.15)
3	6.6Bb (0.15)	6.5Bb (0.15)	11.8Aa (0.30)	8.4B (0.12)	67.7 (2.18)	66.7 (2.18)	74.2 (1.54)	69.5b (1.15)
Mean	8.4b (0.41)	9.35b (0.41)	11.2a (0.30)		72.6 (0.60)	72.60 (0.60)	75.0 (0.43)	
		NDF (%)				ADF (%)		
1	60.4 (2.14)	59.7 (2.14)	59.0 (1.51)	59.7 (1.13)	30.2 (0.97)	30.0 (0.97)	30.3 (0.69)	30.2 (0.51)
2	65.6 (2.14)	62.8 (2.14)	61.6 (1.51)	63.3 (1.13)	31.6 (0.97)	31.9 (0.97)	30.7 (0.69)	31.7 (0.51)
3	62.6 (2.14)	60.3 (2.14)	60.7 (1.51)	60.9 (1.13)	31.3 (0.97)	29.7 (0.97)	31.1 (0.69)	30.7 (0.51)
Mean	62.6 (1.54)	60.95 (1.54)	60.43 (1.09)		31.0 (0.56)	30.8 (0.56)	30.7 (0.56)	

Means followed by the same small letter in lines and same capital letter in columns do not differ ($P > 0.05$). Values within brackets are the standard error of the mean.

with evaluation period ($P = 0.0089$), with lowest values observed during period 3 (Table 5).

4. Discussion

The light environment in CLFI systems is influenced by tree type, density and arrangement, herbage height and phenology (Paciullo et al., 2011; Peri et al., 2007). Because of their upper position relative to forage canopy, tree leaves absorb light preferentially, reducing the amount of photosynthetic active radiation (PAR) that reaches the pasture growing underneath the trees (Feldhake et al., 2005; Garcia et al., 2011). For that reason, it is well established that the presence of trees significantly changes the microclimate, affecting herbage production and morphology of forage plants (Lin et al., 1999; Peri et al., 2006). In this study, the tree densities and arrangements used resulted in 18 to 55% reduction in PAR on MSS and ISS, respectively (Table 1). As the shade intensity increased, there was an increase in pre-grazing sward height (Table 2, Figs. 3, 4 and 5). Herbage mass decreased pre-grazing and post-grazing and grazing interval increased (Table 2). On FS and MS shade regimes, the upper half of the sward was comprised mainly by leaves and the lower half by stems and dead material (Figs. 3 and 4). However, during period 3, the percentage of dead material in the upper half of the sward increased and the percentage of leaves decreased on FS and MS shade regimes (Fig. 5). The changes observed during period 3 may be attributed to shortage of rainfall at that time of the year (Fig. 1).

In general, IS paddocks showed increased stem percentage in the upper half of the sward at pre-grazing relative to FS and MS paddocks (Figs. 3, 4 and 5). The reduction in PAR caused by shading in IS (Table 1) likely resulted in increased stem elongation, causing sward height and percentage of stems in the herbage mass to increase (Table 2, Figs. 3, 4 and 5). Stem elongation was previously reported in shaded swards (Castro et al., 1999; Paciullo et al., 2008; Gobbi et al., 2009) and it was identified as strategy mechanism to overcome light reduction by positioning leaves higher in the sward canopy. Greater stem percentage and sward height were observed on "inside" relative to "outside" paddocks. "Inside" paddocks had longer regrowth periods than "outside" paddocks, which resulted in longer periods of stem elongation (Table 2, Figs. 3, 4 and 5). Longer regrowth has been consistently associated with greater post-grazing height and stem percentage in the herbage mass (Silveira et al., 2013; Pereira et al., 2015).

Changes in weather result in changes in plant morphology that ultimately change the morphological composition of swards (Fagundes et al., 2006; Sousa et al., 2010). At post-grazing, FS paddocks showed greater percentage of leaf during periods 1 and 2 compared to period 3. During period 3, the percentage of dead material increased on FS swards, which may have been associated with the marked reduction in rainfall from period 1 to 3 (Fig. 1). Light restriction resulted in increased stem percentage in the herbage mass and ultimately in the consumed herbage (Table 4). At the end of grazing, stem percentage increased and leaf percentage decreased in the consumed herbage as shading increased (Table 4).

Grazing behavior and consequently herbage intake are influenced by the vertical distribution of morphological components of sward herbage mass (Carvalho et al., 2009; Fonseca et al., 2012). In this study, animals grazing IS paddocks had smaller bite mass and intake rate during periods 1 and 2, both at the beginning and end of grazing (Table 3). This may be the result of the greater stem percentage in the herbage mass (Table 2, Figs. 3, 4 and 5), since this component interferes negatively with herbage apprehension and intake (Drescher et al., 2006; Carvalho et al., 2009). During period 2, lower bite rate was observed at the beginning of grazing for FS and MS relative to IS (approximately 6% reduction). However, intake rate was greater on FS and MS, a consequence of greater bite mass (Table 3). Increased bite mass was also observed on "outside" paddocks relative to "inside" paddocks, at the end of grazing, indicating a positive relationship with the presence of leaf in sward herbage mass (Wade and Carvalho, 2000; Drescher et al., 2006) and the relative greater importance of bite size relative to bite rate in determining the rate of herbage intake (Table 3).

It is well established that the presence of leaves relative to other components in the herbage mass is necessary to fulfill the nutritional needs of the grazing animals (Gontijo Neto et al., 2006). Leaves are the components with highest nutrient concentrations, which, together with high dry matter digestibility, results in increased animal performance (Carvalho et al., 2009). During grazing, as animals remove herbage from the sward, leaf mass decreases relative to stem and dead material, resulting in severe limitations to grazing (Carvalho et al., 2009). Regardless of shade treatment, the top 50% of sward herbage mass was comprised mainly by leaves. As the post-grazing target of 50% of the pre-grazing height was being achieved, the leaf horizon was depleted and stems became a physical resistance to grazing (Benvelutti et al., 2006; Drescher et al., 2006). During period 3, at the beginning of grazing, there were no differences in intake rate among shade regimes (Table 3). During this period, rainfall was lowest (Fig. 1), and resulted in smaller herbage mass with smaller leaf and greater stem and dead material percentages on FS and MS (Table 2, Fig. 5). At the end of grazing, lower intake rate and bite mass were observed on FS (Table 3), likely due to the reduction in leaf and increase in dead material percentage in post-grazing herbage mass (Fig. 5). These conditions resulted in smaller bites and forced animals to harvest herbage with greater dead material percentage (Table 4).

In this experiment, only CP and IVDMD varied with shade regimes and evaluation period (Table 5). Crude protein concentration increased with the increase in shade level, which is consistent with results in the literature (Lin et al., 2001; Kallenbach et al., 2006; Paciullo et al., 2007; Baruch and Guenni, 2007; Sousa et al., 2010; Paciullo et al., 2011). Shaded plants develop slowly when compared to plants under full sunlight, and thus they can be considered physiologically younger, which may have also contributed to increased CP concentration (Paciullo et al., 2011). In addition, shaded plants have thinner cell walls and smaller cells with greater N concentration (Gobbi et al., 2011). The decrease in CP throughout the experiment (Table 5) was likely associated with the increase in dead material percentage in the herbage mass. Despite the increase in sward height and stem percentage on IS paddocks (Table 2, Figs. 3, 4 and 5), no variations in ADF and NDF concentrations were observed. It is possible that the 95% LI grazing strategy prevented the accumulation of fibrous fractions in the herbage, resulting in similar IVDMD for all shade regimes (Table 5). The IVDMD varied only with evaluation period. During period 3, IVDMD was lower (Table %) as a result of increased percentage of dead material in the herbage mass (Fig. 5).

5. Conclusion

Shade regimes MS and FS showed quite similar herbage and animal related responses, indicating that low population of trees and a more open planting arrangement may favor animal production and productivity in CLFI systems. This highlights the importance of strategic planning for combining trees and pastures in an integrated land use proposal.

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References

Baruch, Z., Guenni, O., 2007. Irradiance and defoliation effects in three species of the forage grass *Brachiaria*. Trop. Grasslands 41, 269–276.
Barthram, G.T., 1985. Experimental techniques: the HFRO sward stick. The Hill Farming Research Organization. Biennial Report. HFRO, Mildlothian, pp. 29–30.
Benvenutti, M.A., Gordon, I.J., Poppi, D.P., 2006. The effects of the density and physical properties of grass stems on the foraging behaviour and instantaneous intake rate by cattle grazing an artificial reproductive tropical sward. Grass Forage Sci. 61, 272–281. http://dx.doi.org/10.1111/j.1365-2494.2006.00531.x.
Benvenutti, M.A., Gordon, I.J., Poppi, D.P., Crowther, R., Spinks, w., 2009. The horizontal barrier effect of stem on the foraging behaviour of cattle grazing five tropical grasses. Livest. Sci 126, 229–238. http://dx.doi.org/10.1016/j.livsci.2009.07.006.
Carvalho, M.M., Freitas, V.P., Andrade, A.C., 1995. Crescimento inicial de cinco gramíneas tropicais em um sub-bosque de angico-vermelho (*Anadenanthera macrocarpa* Beth.). Pasturas Tropicales 17, 24–30.
Carvalho, P.C.F., Ribeiro Filho, H.M.N., Poli, C.H.E.C., Moraes, A., Delagarde, R., 2001. Importância da estrutura da pastagem na ingestão e seleção de dietas pelo animal em pastejo. In: Pedreira, C.G.S., Da Silva, SC. (Eds.), A Produção Animal Na Visão Dos Brasileiros. FEALQ, Piracicaba, pp. 853–871.
Carvalho, P.C.F., Trindade, J.K., Da Silva, S.C., Bremm, C., Mezzalira, J.C., Nabinger, C., Amaral, M.F., Carassai, I.J., Martins, R.S., Genro, T.C.M., Gonçalves, E.N., Amaral, G.A., Gonda, H.L., Poli, C.H.E.C., Santos, D.T., 2009. Consumo de forragem por animais em pastejo: analogias e simulações em pastoreio rotativo. Simpósio Sobre Manejo De Pastagem – intensificação de Sistemas De Produção Animal Em Pasto. FEALQ, Piracicaba, pp. 61–93.
Castro, C.R.T.de, Garcia, R., Carvalho, M.M., Couto, L., 1999. Grass forages production cultivated under light reduction. R. Bras. Zootec. 28, 919–927. http://dx.doi.org/10.1590/S1516-35981999000500003.
Dias-Filho, M.B., 2000. Growth and biomass allocation of the C4 grasses Brachiaria brizantha and B. humidicola under shade. Pesq. Agropec. Bras. 35, 2335–2341. http://dx.doi.org/10.1590/S0100-204X2000001200003.
Drescher, M., Heitkonig, I.M.A., Raats, J.G., Prins, H.H.T., 2006. The role of grass stems as structural foraging deterrents and their effects on the foraging behaviour of cattle. Appl. Anim. Behav. Sci. 101, 10–26. http://dx.doi.org/10.1016/j.applanim.2006.01.011.
Fagundes, J.L., Fonseca, D.M., Mistura, C., Moraes, R.V., Vitor, C.M.T., Gomide, J.A., Nascimento Junior, D., Casagrande, D.R., Costa, L.T., 2006. Morphogenetical and structural characteristics of the signalgrass in a nitrogen fertilized pasture evaluated over the seasons of the year. R. Bras. Zootec. 35, 21–29. http://dx.doi.org/10.1590/S1516-35982006000100003.
Feldhake, C.M., Neel, J.P.S., Belesky, D.P., Mathias, E.L., 2005. Light measurement methods related to forage yield in a grazed northern conifer silvipasture in the Appalachian region of eastern USA. Agroforest. Syst. 65, 231–239. http://dx.doi.org/10.1007/s10457-005-1667-2.
Fonseca, L., Mezzalira, J.C., Bremm, C., Filho, R.S.A., Gonda, H.L., Carvalho, P.C.deF., 2012. Management targets for maximizing the short-term herbage intake rate of cattle grazing in Sorghum bicolor. Livest. Sci. 145, 205–211. http://dx.doi.org/10.1016/j.livsci.2012.02.003.
Garcia, A.R., Matos, L.B., Lourenço Junior, J.B., Nahúm, B.S., Araújo, C.V., Santos, A.X., 2011. Physiological features of dairy buffaloes raised under shade in silvipastural systems. Pesq. Agropec. Bras. 46, 1409–1414. http://dx.doi.org/10.1590/S0100-204X2011001000039.
Gobbi, K.F., Garcia, R., Ventrella, M.C., Garcez Neto, A.F., Rocha, C.P., 2011. Specific leaf area and quantitative leaf anatomy of signalgrass and forage peanut submitted to shading. R. Bras. Zootec. 40, 1436–1444. http://dx.doi.org/10.1590/S1516-35982011000700006.
Gobbi, K.F., Garcia, R., Garcez Neto, A.F., Pereira, O.G., Ventrella, M., Rocha, G.C., 2009. Morphological and structural characteristics and productivity of Brachiaria grass and forage peanut submitted to shading. R. Bras. Zootec. 38, 1645–1654. http://dx.doi.org/10.1590/S1516-35982009000900002.
Gomide, C.A.M., Gomide, J.A., Alexandrino, E., 2007. Structural characteristics and forage production of Panicum maximum cv. Mombaça pasture according to rest periods. Pesq. Agropec. Bras. 42, 1487–1494. http://dx.doi.org/10.1590/S0100-204X2007001000017.
Gontijo Neto, M.M., Euclides, V.P.B., Nascimento Junior, D., Miranda, L.F., Fonseca, D.M., Oliveira, M.P., 2006. Effects of herbage allowance on the intake and grazing time of Nellore steers grazing Tanzania grass pasture. R. Bras. Zootec. 35, 60–66. http://dx.doi.org/10.1590/S1516-35982006000100007.
Hodgson, J., 1982. Ingestive behaviour. In: Leaver, J.D. (Ed.), Herbage Intake Handbook. British Grasslands Society, Wallingford, pp. 113–138.
Kallenbach, R.L., Kerley, M.S., Bishop-Hurley, G.J., 2006. Cumulative forage production, forage quality and livestock performance from an annual ryegrass and cereal rye mixture in a Pine-Walnut Silvopastoral. Agroforest. Syst. 53, 43–53. http://dx.doi.org/10.1007/s10457-005-6640-6.
Kenward, M.G., Rogers, J.H., 1997. Small sample inference for fixed effects from restricted maximum likelihood. Biometrics 53, 983–997. http://dx.doi.org/10.2307/2533558.
Lambers, H., Chapim III, F.S., Pons, T.L., 1998. Plant Physiological Ecology. New York.
Lin, C.H., McGraw, R.L., George, M.F., Garret, H.E., 1999. Shade effects on forage crops with potential in temperate agroforestry practices. Agroforest. Syst. 44, 109–119. http://dx.doi.org/10.1023/A:1006205116354.
Lin, C.H., McGraw, R.L., George, M.F., 2001. Nutritive quality and morphological development under partial shade of some forage species eith agroforestry potential. Agroforest.Syst. 53, 269–281. http://dx.doi.org/10.1023/A:1013323409839.
Littel, R.C., Pendergast, J., Natarajan, R., 2000. Modelling covariance structure in the analysis of repeated measures data. Stat. Med. 19, 1793–1819 10.1002/1097-0258(20000715)19:13 ≤ 1793::AID-SIM482 ≥ 3.0.CO,2-Q.
Mabjeesh, S.J., Cohen, M., Ariell, A., 2000. In vitro methods for measuring the dry matter digestibility of ruminant feedstuffs: comparison of methods and inoculum source. J. Dairy Sci. 83, 2289–2294. http://dx.doi.org/10.3168/jds.S0022-0302(00)75115-0.
Martuscello, J.A., Jank, L., Gontijo Neto, M.M., Laura, V.A., Cunha, D.N.F.V., 2009. Produção de gramíneas do gênero Brachiaria sob níveis de sombreamento. Rev. Bras. Zootec 38, 1183–1190 doi:.
Moore, K.J., Dixon, P.M., 2015. Analysis of combined experiments revisited. Agron. J. 107, 763–771. http://dx.doi.org/10.2134/agronj13.0485.
Paciullo, D.S.C., Carvalho, C.A.B., Aroeira, L.J.M., Morenz, N.J.F., Lopes, F.C.F., Rossiello, R.O.P., 2007. Morphophysiology and nutritive value of signalgrass under natural shading and full sunlight. Pesq. Agropec. Bras. 42, 573–579. http://dx.doi.org/10.1590/S0100-204X2007000400016.
Paciullo, D.S.C., Campos, N.R., Gomide, C.A.M., Castro, C.R.T.de, Tavela, R.C., Rossiello, R.O.P., 2008. Growth of signalgrass influenced by shading levels and season of the year. Pesq. Agropec. Bras. 43, 917–923. http://dx.doi.org/10.1590/S0100-204X2008000700017.
Paciullo, D.S.C., Castro, C.R.T., Gomide, C.A.M., 2011. Performance of dairy heifers in a silvopastoral system. Livest. Sci. 141, 166–172. http://dx.doi.org/10.1016/j.livsci.2011.05.012.
Pereira, L.E.T., Paiva, A.J., Guarda, V.D., Pereira, P.M., Caminha, F.O., Da Silva, S.C., 2015. Herbage utilization efficiency of continuously stocked marandu palisade grass subjected to nitrogen fertilization. Sci. Agric. 72, 114–123. http://dx.doi.org/10.1590/0103-9016-2014-0013.
Peri, P.L., Lucas, R.J., Moot, D.J., 2007. Dry matter production, morphology and nutritive value of *Dactylis glomerata* growing under different light regimes. Agroforest. Syst 70, 63–79. http://dx.doi.org/10.1007/s10457-007-9029-x.
Peri, P.L., Moot, D.J., McNeil, D., 2006. Validation of a canopy photosynthesis model for cocksfoot pastures grown under different light regimes. Agroforest. Syst. 67, 259–272. http://dx.doi.org/10.1007/s10457-005-3825-y.
Peri, P.L., Varella, A.C., Lucas, R.J., Moot, D.J., 2001. Cocksfoot and Lucerne productivity in Pinus radiata silvopastoral system: a grazed comparison. Proc. NZ Grassl. Assoc. 63, 139–147.

Silveira, M.C.T., Da Silva, S.C., Souza Junior, S.J., Barbero, L.M., Rodrigues, C.S., Limão, V.A., Pena, K.S., Nascimento Júnior, D., 2013. Herbage accumulation and grazing losses on Mulato grass subjected to strategies of rotational stocking management. Sci. Agric. 70, 242–249. http://dx.doi.org/10.1590/S0103-90162013000400004.
Taxonomy, Soil, 1999. A Basic System of Soil Classification for Making and Interpreting Soil Surveys, Second Ed. United States Department of Agriculture Nature Resources Conservation Serve – USDA.
Sollenberger, L.E., Burns, J.C., 2001. Canopy characteristics, ingestive behavior and herbage intake in cultivated tropical grasslands. ´Proceedings International Grassland Congress´. Editora IGC, São Pedro, pp. 321–327.
Sousa, L.F., Maurício, R.M., Moreira, G.R., Gonçalvez, L.C., Borges, I., Pereira, L.G.R., 2010. Nutritional evaluation of “Brachiarão” grass in association with “Aroeira” trees in a silvopastoral system. Agroforest. Syst. 79, 189–199. http://dx.doi.org/10.1007/s10457-010-9297-8.
Trindade, J.K., Da Silva, S.C., Souza Junior, S.J., Giacomini, A.A., Zeferino, C.V., Carvalho, P.C.F., 2007. Morphological composition of the herbage consumed by beef cattle during the grazing down process of marandu palisadegrass subjected to rotational strategies. Pesq. Agropec. Bras. 42, 883–890. http://dx.doi.org/10.1590/S0100-204X2007000600016.
Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Symposium: carbohydrate methodology, metabolism, and nutritional implications in dairy cattle. J. Dairy Sci. 74, 3583–3597. http://dx.doi.org/10.3168/jds.S0022-0302(91)78551-2.
Young, A, 1991. Agroforestry for Soil Conservation. ICRAF, Nairobi, pp. 176 p.
Wade, M.H., Carvalho, P.F., 2000. Defoliation patterns and herbage intake in grazed pastures. In: Lemaire, G., Hodgson, J., De Moraes, A., Carvalho, P.C.F., Nabinger, C. (Eds.), Ecophysiology of Grasslands and the Ecology of Grazing. CABInternatinal, Oxford, pp. 233–248.
Warren Wilson, J., 1960. Inclined point quadrat. New Phytol 58, 92–101. http://dx.doi.org/10.1111/j.1469-8137.1960.tb06195.x.