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Forage dry mass accumulation and structural characteristics of Piatã grass in silvopastoral systems in the Brazilian savannah

Darliane de Castro Santos[a,*], Roberto Guimarães Júnior[b], Lourival Vilela[b], Karina Pulrolnik[b], Vinicius Bof Bufon[b], Aldi Fernandes de Souza França[a]

[a] Department of Animal Production, Federal University of Goiás, Campus Samambaia, Avenida Esperança, s/n, Campus Universitário, CEP: 74.690.900, Goiânia, GO, Brazil
[b] Embrapa Cerrados (Brazilian Agricultural Research Corporation), Rodovia BR-020, Km 18 Caixa Postal: 08223, CEP: 73310-970, Planaltina, DF, Brazil

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A B S T R A C T

The presence of trees in silvopastoral systems causes changes in the microclimate of the understory where there is the cultivation of forages. This study evaluated the forage dry mass and the structural characteristics of Piatã grass under two densities of trees in a silvopastoral system, in contrast to a treeless area in the rainy and dry seasons of the Brazilian savannah region, so called Brazilian Cerrado. The forage was *Brachiaria brizantha* cv. BRS Piatã and the tree species was the eucalyptus (*Eucalyptus grandis* × *E. urophylla*) planted in the North-South direction in the treatments: forage grown in treeless area (control); forage grown in eucalyptus understory with spacing between rows of 22 m (SSP22); forage grown in eucalyptus understory with spacing between rows of 12 m (SSP12). The experimental design was a randomized complete block with three replications and evaluations conducted from April 2013 to April 2014. There was a reduction in cumulative dry mass and in accumulation rate of Piatã grass in silvopastoral system in the rainy season and the Western side suffered greater interference from trees during this season. For every 1% reduction in photosynthetically active radiation occurred a decrease of 1.35% in the forage dry mass, corresponding to 42.8 kg ha^{-1}. The structural characteristics of Piatã grass have changed in both dry and rainy seasons in silvopastoral system. The spacing between rows of *Eucalyptus* greater than 22 m is less damaging for pasture productivity when the trees of the silvopastoral system are planted in North-South direction.

1. Introduction

The Brazilian savannah region, so called Brazilian Cerrado, comprises a total area of 204.7 million hectares, equivalent to 24% of the Brazilian territory, with tropical climate and well-defined dry and rainy seasons, with annual rainfall around 1500 mm and average annual temperature between 21.3 and 27.2 °C (Alvarenga et al., 2011). The area with planted pastures in this region is equivalent to 60 million hectares, of which 51 million hectares, i.e., 85% are composed of *Brachiaria* forages (Macedo, 2005). Cattle breeding in Brazil is mostly on pasture and, over the years, the soils were used without adequate replenishment of nutrients, which resulted in cases of pasture degradation.

A pasture is considered degraded when there is a marked decrease in ideal agricultural productivity (reduction in the ideal carrying capacity), and the most important factors related to this degradation include the inadequate animal management and the lack of nutrient replenishment (Macedo, 2009; Dias-Filho, 2011). Around 70% of the total pasture areas in the country are degraded or under degradation, and concentrated in the North, Central–West and Northeast regions (Dias-Filho, 2014). An alternative to the restoration of these degraded pastures or under degradation is the implementation of agroforestry systems like silvopastoral systems (Dias-Filho, 2011). These systems besides restoring degraded pastures, seek synergistic effects between agroecosystem components, encompassing the environmental suitability, the valuation of the man and the economic viability (Barcellos et al., 2011).

However, the presence of trees causes changes in the microclimate of the understory where there is the cultivation of forage crops. The tree canopy architecture affects production of understory layers, by producing different microclimatic conditions which influence pasture yield and its seasonal pattern

* Corresponding author.
E-mail addresses: darliane.castro@hotmail.com (D.d.C. Santos), roberto.guimaraes-junior@embrapa.br (R. Guimarães Júnior), lourival.vilela@embrapa.br (L. Vilela), karina.pulrolnik@embrapa.br (K. Pulrolnik), vinicius.bufon@embrapa.br (V.B. Bufon), aldi@vet.ufg.br (A.F.d.S. França).

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(Silva-Pando et al., 2002). When compared to a treeless system, silvopastoral system provides reduction of solar radiation and wind speed and as a result, there is a reduction in the maximum temperature in sites close to trees and higher humidity at the center of the spacing between rows (Pezzopane et al., 2015). In addition, there is greater soil moisture removal near the tree row in comparison to the center of the spacing between rows, mainly due to greater exploration of the roots of trees at greater depths (Pezzopane et al., 2015). Among these changes, the limitation of photosynthetically active radiation is the major constraint to production of dry matter when there are no problems with water deficit in soil (Burner and Belesky, 2008). The tree component influences most pasture characteristics in silvopastoral system, according to its distance from the tree row (Paciullo et al., 2011). There are significant differences in quality and amount of solar radiation in the understory in this system due to the spatial arrangement and density of trees (Rodrigues et al., 2014).

In the most conventional and denser arrangements of eucalyptus (3 m × 2 m and 3 m × 3 m), from a certain age, it is not possible to practice intercropping between the rows due to space limitations, physical suppression from litter, competition for water and nutrients and also by low light availability (Oliveira et al., 2007). However, the larger space between the rows when using broader arrangements becomes an advantage for the practice of intercropping (Oliveira et al., 2007).

Brachiaria brizantha (Hochst. ex A. Rich.) R. D. Webster cv. BRS Piatã (Piatã grass) is a perennial forage grass. In perennial forage, unlike annual crops where grains are collected at the end of the plant cycle, leaf area removal should be carried out at time intervals during the development of the crop (Rodrigues et al., 2012). Some studies have been done with *Brachiaria* in order to understand the behavior of this forage in silvopastoral systems (Paciullo et al., 2007; Soares et al., 2009; Gómez et al., 2012; Oliveira et al., 2014), however, further research should be conducted, so as to generate technical coefficients that support decision-making of farmers who choose to use this system.

In this context, this study evaluate the forage dry mass accumulation and the structural characteristics of Piatã grass under two densities of tress in a silvopastoral system, in contrast to a treeless area in the rainy and dry seasons of the Brazilian Cerrado.

2. Material and methods

2.1. Study area and treatments

The study was conducted at Embrapa Cerrados (Brazilian Agricultural Research Corporation) located in Planaltina, Federal District, Brazil (15°36′36.31″ S 47°42′11.63″ W, 987 m altitude) with 1383.7 mm average annual rainfall, 21.9 °C average annual temperature and rainy tropical climate Awa (A—rainy tropical

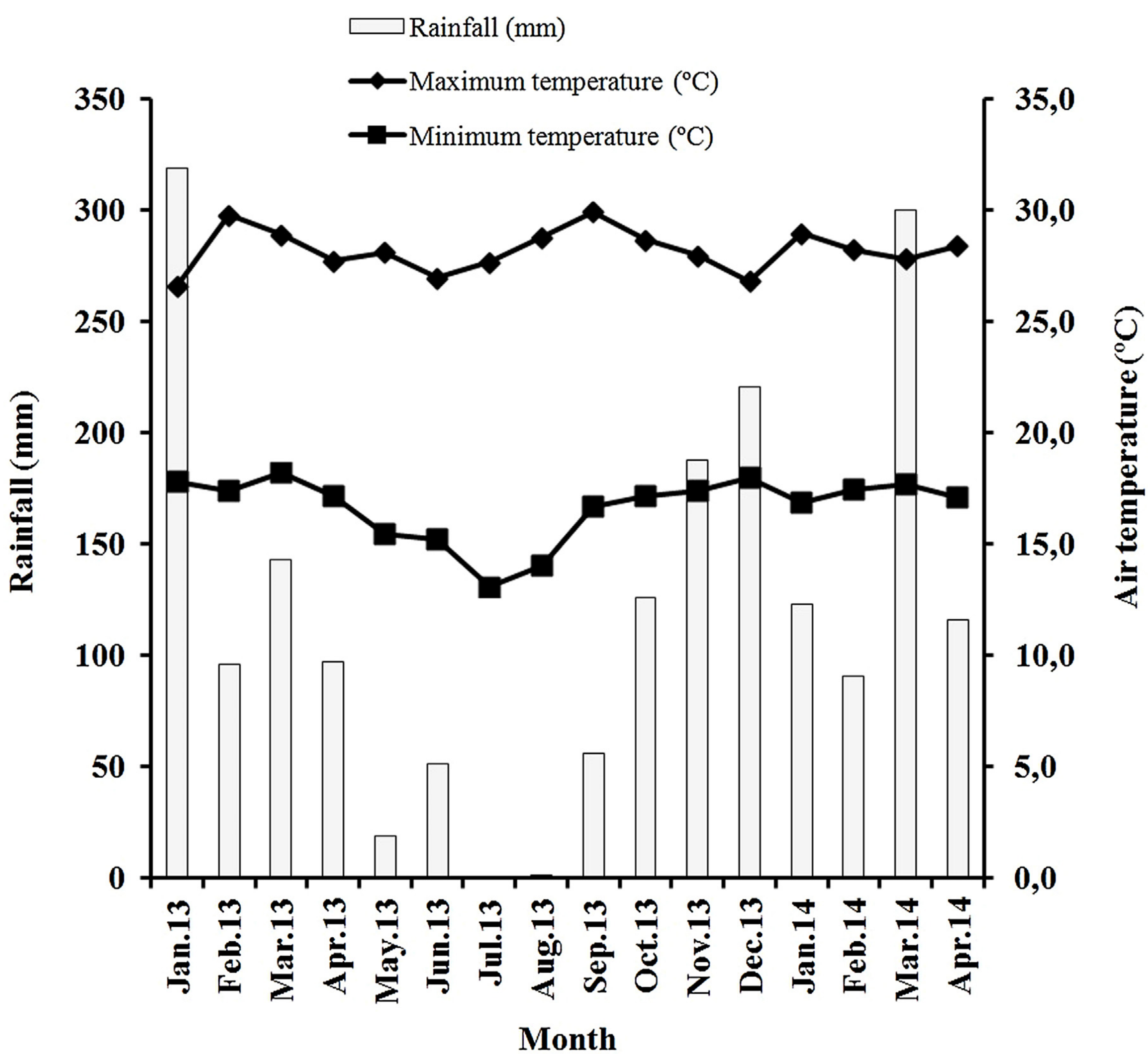

Fig. 1. Monthly mean temperatures and rainfall from January 2013 through April 2014 in the experimental area of Embrapa Cerrados.

climate; w—summer rain, a—hot summer, with average temperatures of the hottest month above 22 °C) (Silva et al., 2014). The Cerrado is characterized by two well-defined seasons, namely, rainy and dry (which has soil water deficit and lower temperatures) as can be seen in Figs. 1 and 2. With respect to physical characteristics, the soil of the experimental area was composed of 22% fine sand, 5% coarse sand, 60% clay and 13% silt. In relation to the chemical characteristics, phosphorus content was 4.42 mg L-1, potassium content was 75.11 mg L-1, exchangeable aluminum content was 0.13 100cc-1, content of hydrogen + aluminum (H + Al) was 1.38 me 100cc-1, organic matter content was 3.77% and pH (in water) was 5.98.

The experimental area of Embrapa Cerrados, where this study was carried out, has been used in long-term studies with crop-livestock-forest integration system and crop-livestock (in treeless areas). The tree component was composed of eucalyptus urograndis (*Eucalyptus grandis* × *E. urophylla*) planted in rows composed of two rows of trees (2 m × 2 m spacing). Planting of eucalyptus seedlings was held in February 2009 in the North-South direction, depending on the direction of the slope (East–West), aiming to prevent surface erosion. This planting was carried out intercropped with sorghum (*Sorghum bicolor*) planted in the spacing between the rows. In the second and third year (2009–2011), agricultural activity remained in the eucalyptus understory with late soybean crop (*Glycine max* L.). In the fourth year (2011–2012), it was sown a cultivar of early soybean and, after harvesting, sorghum was intercropped with *Brachiaria brizantha* cv. BRS Piatã. For sorghum, it was used a seeding rate of 8 kg ha^{-1} seed, and for Piatã grass, 5 kg pure and viable seeds (PVS) per hectare. Forage seeds were sown by broadcast seeding just before the sorghum planting. Planting fertilization of sorghum intercropped with Piatã grass was performed with the N-P-K formulation (08-20-15) at 350 kg ha^{-1}. After harvesting the sorghum, Piatã grass was planted in the area thus beginning the silvipastoral phase of the project, object of study of this work.

In March 2013, grass was subject to standardization cutting with the aid of a horizontal straw chopper and nitrogen topdressing at 92 kg ha^{-1} of nitrogen as urea. Another nitrogen fertilization was held in February 2014 at 60 kg ha^{-1} of nitrogen as urea.

The treatments consisted of (i) forage grown in a treeless area (control); (ii) forage grown in eucalyptus understory with a spacing of 2 m × 2 m (double row) and a spacing between rows of 22 m, totaling 417 trees per hectare (SSP22); (iii) forage grown in eucalyptus understory with a spacing of 2 m × 2 m between trees (double row) and a spacing between rows of 12 m, totaling 715 trees per hectare (SSP12). The experimental area received the same fertilization and crops before the beginning of silvopastoral phase. The reduction of photosynthetically active radiation in the treatments under silvopastoral system was 21.9% in SSP22 and 39.5% in SSP12 (measurements were held with clear sky on 28.08.2013 and 09.01.2014 at 12 h). Average height and diameter at breast height (DBH) of eucalyptus trees in 2013 were 17.8 m and 14.1 cm, respectively. The experimental period was from April 2013 to April 2014.

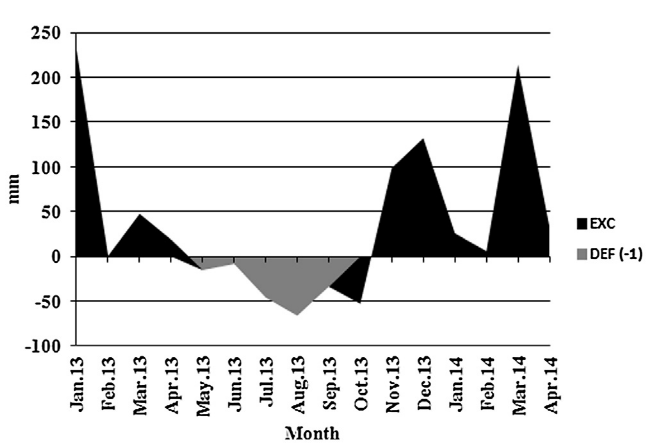

Fig. 2. Water balance (Thornthwaite and Mather, 1955) from January 2013 through April 2014 in the experimental area of Embrapa Cerrados.

The experimental design was a randomized complete block with three treatments and three replications. The area in each repetition was 1.3 ha totaling a total experimental area of 11.7 ha. The effective area with Piatã grass (excluding the area with trees) was 1.3 ha, 1.2 ha and 0.9 ha for the treatments control, SSP22 and SSP12 respectively. Although the effective area has been different, all results are presented per hectare of the system for a correct comparison between the treatments.

The paddocks were grazed by Nellore cattle heifers (*Bos indicus*) with average weight of 317 kg ± 87 kg. Nellore is a breed of cattle widely used in Brazil for meat production. Continuous grazing with variable stocking rate (put and take method) was adopted. Six animals (testers) per treatment remained throughout the trial period. After every pasture evaluation period, non-tester heifers were put or removed in each paddock to keep the equal forage supply among treatments. We adopted a forage supply of 10 kg forage dry mass to 100 kg animal live weight per day on the effective area of pasture (excluding the area with trees) for all treatments in April 2013, June–July 2013, and October-November 2013; 9 kg forage dry mass per 100 kg animal live weight per day in February 2014 and March 2014 and 8 kg forage dry mass per 100 kg animal live weight per day in May 2013, August-September 2013 December 2013, January 2014 and April 2014. This variation in supply was due to the variation in forage dry matter availability in different periods of the year.

2.2. Cumulative forage dry mass and accumulation rate

To estimate the cumulative forage dry mass, 11 samplings were conducted as follows: 1st (01.04.2013); 2nd (29.04.2013); 3rd (27.05.2013); 4th (15.07.2013); 5th (09.09.2013); 6th (11.11.2013); 7th (10.12.2013); 8th (13.01.2014); 9th (10.02.2014); 10th (17.03.2014) and 11st (22.04.2014). Sampling was carried out, on average, every 28 days during the rainy season and 56 days during the dry season. The longest interval used during the dry season was due to the smaller growth of forage at that time of the year.

For the evaluations of cumulative forage dry mass, we used exclusion cages (1 m^2), using the triple pairing technique (Moraes et al., 1990), in which forage samples were taken 5 cm from the ground. The cages were used to isolate the spots assessed given the presence of cattle under continuous grazing in the experimental area. On the first day of allocation of the cages, we selected, by visual criteria, two areas similar in dry matter of Piatã grass, representing the paddock condition. In an area, we placed the cage, and in the other, we performed the sampling of 1 m^2 (paired sample) at 5 cm from the ground, in order to obtain an estimate of the initial dry mass of Piatã grass inside the cage. The total volume of fresh mass sampled in the field was weighed and subsamples of approximately 500 g were separated and dried in a forced air ventilation oven at 65 °C for 72 h to obtain the dry weight to calculate the dry mass (kg ha^{-1}).

Cumulative dry mass (kg ha^{-1}) of Piatã grass was obtained by the difference between the forage dry mass of the sample taken inside the cage on the date of sampling and the forage dry mass of the sample outside the cage (paired sample) on the date of the previous sampling. We also calculated the accumulation rate (kg ha^{-1} day^{-1}) of forage by dividing the cumulative forage dry mass in each period sampled by the number of days between evaluations.

Six cages were placed in paddocks corresponding to the treatments control (no tree) and SSP12. In the paddocks of the treatment SSP22, eight cages were placed, aiming to cover the greatest distance between the tree rows. In paddocks of the control, the arrangement of the samples was made at random. In areas with eucalyptus (SSP22 and SSP12), cages were placed at the center of the spacing between the rows and also 2 m away from the trees, since the forage dry mass is different at these sites (Fig. 3).

An evaluation aimed at understanding the effect of the location of the forage in the spacing between rows on the accumulation of forage dry mass also on the structural characteristics of Piatã grass. Samples were taken 2 m from the trees, whose sides were called West and East (corresponding to the arrangement of the site on the ground in relation to the tree row) and also at the center of the spacing between tree rows, called Center (Fig. 3). The reduction of photosynthetically active radiation (PAR) at each site in the treatments under silvopastoral system (SSP22 and SSP12) can be observed in Table 1.

2.3. Structural characteristics

Assessments were made for leaf area index (LAI), specific leaf area (SLA), leaf width and plant height of Piatã grass. LAI, SLA and leaf width were estimated in subsamples of total forage mass using a leaf area integrator (LI-COR Inc., Lincoln, NE, USA) LI-3100C Area Meter. After reading, leaves were oven-dried at 65 °C for 72 h to determine the dry weight. LAI was evaluated in m^2 leaf per m^2 soil and SLA in $cm^2\,g^{-1}$, calculated from the ratio between leaf area and dry weight of leaves of each sample.

Canopy height was measured inside the exclusion cages, with three readings, and then calculated the average of these values. Height was measured from ground level to the insertion of the last fully expanded leaf.

2.4. Relationship between photosynthetically active radiation available and Piatã grass dry mass availability

The relationship between PAR and the dry mass availability of Piatã grass was also evaluated. For the measurement of PAR, we used a ceptometer (AccuPAR LP-80). Measurements were held with clear sky on 28.08.2013 and 09.01.2014 at 12 h. In areas with presence of trees, the measurements were made close to the tree line and also at the center of alleys, being considered for the analysis the average radiation of these points. To estimate forage availability, we collected ten random samples of 1 m^2 in each paddock, cut 5 cm from the ground on 09.09.2013 and 13.01.2014. The radiation use efficiency (RUE) was calculated by dividing the dry weight of forage for available PAR. For silvopastoral systems, the average of RUE for the two treatments was calculated to be compared to control to understand the effect of reducing PAR in this variable.

Table 1
Reduction of photosynthetically active radiation available (PAR)[a], compared to the control (no trees), at each location in treatments in silvopastoral system.

Treatment	Location	PAR reduction (%)
SSP22	West	78.8
	Center	5.1
	East	43.6
SSP12	West	73.3
	Center	17.7
	East	56.0

[a] Mean of measurements held with clear sky on 28.08.2013 and 09.01.2014 at 12 h.

2.5. Statistical analysis

Data were analyzed in a randomized complete block design with repeated measurements over time, considering the season (rainy and dry) as the repeated factor, using the GLIMMIX procedure of SAS 9.4. For analysis of cumulative forage dry matter, accumulation rate and structural characteristics of Piatã grass, the treatment was considered as fixed effect (2 ° of freedom—DF); the season, as fixed effect (1 DF); the block, as a random effect (2 DF) and the residue, also as random. The error structures investigated were chosen according to the Corrected Akaike Information Criterion (CAIC). For cumulative forage dry matter and forage accumulation rate, we chose the covariance structure composed symmetry (cs). For leaf width and plant weight, we selected the heterogeneous composed symmetry (csh). For LAI, we used the first order autoregressive (ar(1)) and for SLA, the independent, unequal variance (un(1)). For comparison of mean values, we used the Tukey's test and significance at $p \leq 0.05$.

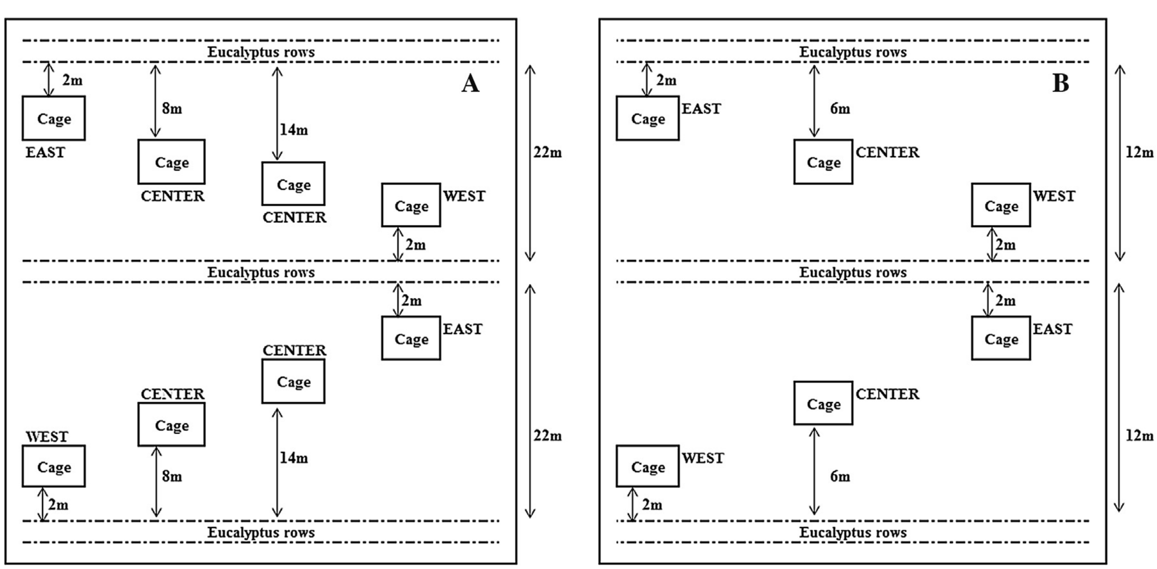

Fig. 3. Arrangement of exclusion cages in treatments SSP22 (A) and SSP12 (B).

Table 2
Plant height (m) and leaf width (cm) of Piatã grass (mean ± standard error of the mean) in a treeless area (control) and in silvopastoral system with eucalyptus urograndis with spacing between rows at 22 m (SSP22) and 12 m (SSP12) in the rainy and dry seasons.

Treatment	Rainy season	Dry season[a]	Mean
Plant height (m)			
Control	0.6 ± 0.06	0.5 ± 0.03	0.5 ± 0.02 a[b]
SSP22	0.7 ± 0.03	0.4 ± 0.03	0.6 ± 0.10 a
SSP12	0.6 ± 0.02	0.5 ± 0.01	0.6 ± 0.07 a
Mean	0.6 ± 0.03 A	0.5 ± 0.02 B	
Leaf width (cm)			
Control	1.7 ± 0.08	1.6 ± 0.05	1.7 ± 0.05 a
SSP22	1.6 ± 0.03	1.3 ± 0.04	1.5 ± 0.15 a
SSP12	1.6 ± 0.02	1.3 ± 0.09	1.5 ± 0.15 a
Mean	1.6 ± 0.03 A	1.4 ± 0.10 B	

[a] Dry: was considered, on the basis of soil water balance, the assessment performed under water deficit.
[b] Means followed by different uppercase letters, in the same row, and lowercase letters, in the same column, are significantly different by Tukey's test at 5% probability.

The dry season was considered, on the basis of soil water balance, the assessment performed under water deficit (Fig. 2). Thus, samples taken in May, June, July, August and September 2013 were considered as representing the dry season. The others were included in the rainy season. For cumulative forage dry mass, we summed up the value obtained for each sampling and presented value of cumulative dry mass of Piatã grass for the rainy season and the other for the dry season. For the other variables, we calculated the mean value of data of samplings referring to each season.

For analysis of the effect of sampling site on the variables studied, data were analyzed in a split plot randomized block design, the main plot being the spatial arrangement of trees (SSP12 and SSP22) and the subplot the site in the spacing between rows (West, Center and East) using the GLIMMIX procedure of SAS 9.4. The investigated error structures were chosen according to the Corrected Akaike Information Criterion (AICC). The covariance structure composed symmetry (CS) was selected for the cumulative dry mass, accumulation rate, LAI, SLA and leaf width. As for the plant height, the covariance structure chosen was the banded main diagonal (un (1)). For comparison of mean values, we used the Tukey's test and significance at $p \leq 0.05$.

For the relationship between the dry mass of Piatã grass and PAR, a regression analysis was run considering as dependent variable the forage dry mass and as independent variable, the PAR. PAR of 28.08.2013 was related to the forage dry mass availability of 09.09.2013 and the PAR of 09.01.2014 was related to the forage dry mass availability of 13.01.2014.

Table 3
Plant height (m) of Piatã grass (mean ± standard error of the mean) in silvopastoral system with eucalyptus urograndis with spacing between rows at 22 m (SSP22) and 12 m (SSP12) in the sides West, Center and East in relation to the tree row.

Treatment	West	Center	East	Mean
Rainy season				
SSP22	0.6 ± 0.02	0.7 ± 0.02	0.6 ± 0.05	0.7 ± 0.02 a
SSP12	0.6 ± 0.02	0.6 ± 0.01	0.6 ± 0.02	0.6 ± 0.02 a
Mean	0.6 ± 0.01 A	0.7 ± 0.02 A	0.6 ± 0.02 A	
Dry season				
SSP22	0.5 ± 0.04	0.5 ± 0.04	0.4 ± 0.04	0.4 ± 0.02 b
SSP12	0.5 ± 0.02	0.6 ± 0.03	0.5 ± 0.01	0.5 ± 0.01 a
Mean	0.5 ± 0.03 A	0.5 ± 0.05 A	0.5 ± 0.05 A	

Means followed by different uppercase letters, in the same row, and lowercase letters, in the same column, within the same season, are significantly different by Tukey's test at 5% probability.

Table 4
Leaf width (cm) of Piatã grass (mean ± standard error of the mean) in silvopastoral system with eucalyptus urograndis with spacing between rows at 22 m (SSP22) and 12 m (SSP12) in the sides West, Center and East in relation to the tree row.

Treatment	West	Center	East
Rainy season			
SSP22	1.8 ± 0.03 Aa	1.7 ± 0.03 Aa	1.6 ± 0.02 Aa
SSP12	1.6 ± 0.13 Aa	1.7 ± 0.04 Aa	1.7 ± 0.04 Aa
Dry season			
SSP22	1.3 ± 0.14	1.4 ± 0.05	1.3 ± 0.05
SSP12	1.2 ± 0.10	1.3 ± 0.08	1.2 ± 0.11
Mean	1.3 ± 0.06 AB	1.4 ± 0.05 A	1.2 ± 0.02 B

Means followed by different uppercase letters, in the same row, and lowercase letters, in the same column, within the same season, are significantly different by Tukey's test at 5% probability.

3. Results

3.1. Structural characteristics

For plant height, leaf width and LAI, no significant effect was found for the interaction treatment*season. Regarding the plant height and the leaf width, significant differences were observed only between seasons ($p < 0.05$), with the highest value for the rainy season (Table 2). When analyzing the height according to the site in the spacing between eucalyptus rows, the interaction treatment*site was not significant. In this case, plant height varied according to the treatment only in the dry season (Table 3) with superiority of SSP12 in relation to treatment SSP22 ($p = 0.02$).

When analyzed the width according to the site in the spacing between eucalyptus rows, in the rainy season, there was a significant interaction between treatment*site ($p = 0.03$), however it was not possible to verify differences between treatments within the sites (Table 4). In the dry season, there was variation according to the site ($p = 0.03$) (Table 4).

Regarding the LAI, significant differences were detected between treatments ($p = 0.02$) and the treeless treatment (control) showed higher value compared to SSP12 (Table 5). Higher value of LAI was found in the rainy season ($p \leq 0.05$) (Table 5). With respect to specific leaf area (SLA), there was significant interaction treatment*season ($p \leq 0.05$). SLA was higher for SSP12 in the rainy season, and in the treeless treatment (control) there was a reduction of 25.2% in SLA, and in SSP22, there was a reduction of 13.3% (Table 6). In the dry season, SSP12 treatment showed higher values than the treeless treatment (control). All treatments had reduced SLA in the dry season ($p \leq 0.05$) (Table 6).

As for the LAI depending on the site in the spacing between eucalyptus rows, the interaction treatment*site was not significant. At the center of the spacing between eucalyptus rows, we found the highest value of LAI both in the dry ($p \leq 0.05$) and in the

Table 5
Leaf area index (cm) of Piatã grass (mean ± standard error of the mean) in a treeless area (control) and in silvopastoral system with eucalyptus urograndis with spacing between rows at 22 m (SSP22) and 12 m (SSP12) in the rainy and dry seasons.

Treatment	Rainy season	Dry season[a]	Mean
Control	3.0 ± 0.16	1.9 ± 0.32	2.5 ± 0.55 a[b]
SSP22	2.6 ± 0.14	1.5 ± 0.09	2.1 ± 0.55 ab
SSP12	2.0 ± 0.07	1.1 ± 0.03	1.6 ± 0.45 b
Mean	2.5 ± 0.29 A	1.5 ± 0.23 B	

[a] Dry: was considered, on the basis of soil water balance, the assessment performed under water deficit.
[b] Means followed by different uppercase letters, in the same row, and lowercase letters, in the same column, are significantly different by Tukey's test at 5% probability.

Table 6
Specific leaf area ($cm^2 g^{-1}$) of Piatã grass (mean ± standard error of the mean) in a treeless area (control) and in silvopastoral system with eucalyptus urograndis with spacing between rows at 22 m (SSP22) and 12 m (SSP12) in the rainy and dry seasons.

Treatment	Rainy season	Dry season[a]
Control	176.3 ± 0.9 Ac[b]	114.2 ± 2.2 Bb
SSP22	204.5 ± 7.4 Ab	120.0 ± 1.4 Bab
SSP12	235.8 ± 6.1 Aa	133.5 ± 4.1 Ba

[a] Dry: was considered, on the basis of soil water balance, the assessment performed under water deficit.
[b] Means followed by different uppercase letters, in the same row, and lowercase letters, in the same column, are significantly different by Tukey's test at 5% probability.

rainy season ($p \leq 0.05$) (Table 7). Comparing the LAI of the center with the sides West and East, there was an increase of 19.2% and 15.4% in the rainy season, respectively. In the dry season, the increase was 31.3% for both sides. The treatment SSP22 exhibited higher LAI value in the rainy season ($p = 0.049$) (Table 7).

In silvopastoral systems, SLA varied depending on the effects of treatments in the rainy season ($p = 0.02$) and according to the site in rainy ($p = 0.03$) and dry ($p \leq 0.05$) seasons. The variation according to the treatment in the rainy season presented higher values of SLA for SSP12 (Table 7). But when considered the effect of site, in the rainy season, SLA was higher in the West side compared to the East side (Table 7). In the dry season, the highest SLA was found at the center of the spacing between eucalyptus rows (Table 7).

3.2. Piatã grass forage accumulation

The effect of the interaction treatment*season was significant for cumulative dry mass ($p \leq 0.05$) and accumulation rate ($p \leq 0.05$) of Piatã grass. The accumulation rate in the treeless treatment (control) was significantly higher in the rainy season ($p \leq 0.05$), with no significant difference between SSP22 and SSP12 (Table 8). In turn, in the dry season, there was no significant differences between treatments, all of them showed a reduction in forage accumulation rate: 76.7% in the control treatment, 67.8% in the SSP22 treatment and 63.5% in the SSP12 treatment, when compared with the rainy season ($p \leq 0.05$).

There was a significant difference between treatments for cumulative forage dry mass in the rainy season ($p \leq 0.05$) (Table 8). In this season, the treeless treatment (control) had the highest value of cumulative forage dry mass, followed by SSP22 and SSP12, but with no significant difference between the SSP22 and SSP12 treatments (Table 8). The reduction in cumulative forage dry mass in the rainy season due to the presence of trees was 50.5% and 67.5% for SSP22 and SSP12, respectively. In the dry season, there was no difference between treatments. All treatments showed a reduction in cumulative forage dry mass in the dry season when compared with the rainy season ($p = 0.05$) (Table 8). The percentage of cumulative forage dry mass in the rainy and dry seasons, compared to the total cumulative for the year, for the treeless treatment (control) was 85.1% and 14.9%, respectively. For the SSP22, the value was 76.8% and 23.2% and for the SSP12, 76.2% and 23.8%, for the rainy and dry seasons, respectively.

When analyzed within the silvopastoral systems, there was variation between treatments ($p = 0.03$) and sites ($p = 0.05$) for forage accumulation rate in the rainy season. Between the treatments, the highest value was found for SSP22 (Table 9). As for the site, in rainy season the highest value was registered for the center of the spacing between eucalyptus rows when compared with the West side (Table 9). These results show that in rainy season the forage accumulation rate of the center was twice as high in relation to the West side. In the dry season, there were no significant differences (Table 9).

In the treatments with silvopastoral systems, the spacing between rows affected the cumulative dry mass, and, between treatments, the SSP22 showed higher cumulative forage dry mass in both seasons with a mean value of 5774 kg ha^{-1} in the rainy season (52.1% higher when compared the SSP12; $p = 0.03$) and 1747 kg ha^{-1} in the dry season (47.3% higher when compared to SSP12; $p \leq 0.05$) (Table 9). Regarding the site of sampling, during the rainy season, the cumulative forage dry mass in the center of the spacing between eucalyptus rows was 2.01 times higher than in the West side ($p \leq 0.05$). In the dry season, there were no significant differences between sites (Table 9).

3.3. Relationship between photosynthetically active radiation available and forage dry mass

The dry mass of Piatã grass increased linearly with increasing values of photosynthetically active radiation available (PAR) (Fig. 4A), which were higher in the treeless treatment (control). The linear model was fitted ($p = 0.05$) with a R^2 of 0.70.

The radiation use efficiency (RUE) in the dry season was higher in the control treatment compared with the average of treatments in silvopastoral system (Shaded; Fig. 4B). In the rainy season there was no significant difference between control and shaded (Fig. 4B).

By drawing a relationship between PAR and forage dry mass, the treeless treatment (control) with the mean forage dry mass and the mean PAR of the two treatments with eucalyptus, we observed that for each 1% PAR reduction, there is a decrease of 1.35% in forage dry mass. This value corresponded to 42.8 kg ha^{-1}.

4. Discussion

With increasing shading, the red/far-red ratio decreases (Taiz and Zieger, 2009), leading the plants to direct most of their resources to growth in height. The increase in height caused by shading agrees with the results obtained elsewhere (Paciullo et al., 2008; Castro et al., 2009). However, in this work, plant height was not influenced by the silvopastoral system, but only by the season

Table 7
Leaf area index (cm) and specific leaf area ($cm^2 g^{-1}$) of Piatã grass (m^2 leaf m^{-2} soil) in silvopastoral system with eucalyptus urograndis with spacing between rows at 22 m (SSP22) and 12 m (SSP12) in the sides West, Center and East in relation to the tree row.

Treatment	West	Center	East	Mean
Leaf area index (cm)				
Rainy season				
SSP22	2.4 ± 0.04	3.0 ± 0.21	2.2 ± 0.21	2.5 ± 0.22 a
SSP12	1.8 ± 0.07	2.2 ± 0.08	2.1 ± 0.15	2.0 ± 0.12 b
Mean	2.1 ± 0.26 B	2.6 ± 0.36 A	2.2 ± 0.10 B	
Dry season				
SSP22	1.1 ± 0.09	1.8 ± 0.11	1.3 ± 0.20	1.4 ± 0.20 a
SSP12	1.1 ± 0.06	1.3 ± 0.04	1.0 ± 0.07	1.1 ± 0.10 a
Mean	1.1 ± 0.04 B	1.6 ± 0.23 A	1.1 ± 0.14 B	
Specific leaf area ($cm^2 g^{-1}$)				
Rainy season				
SSP22	205.2 ± 4.0	203.2 ± 7.1	199.9 ± 11.7	202.8 ± 1.6 b
SSP12	250.7 ± 4.5	233.2 ± 3.4	230.6 ± 10.4	238.2 ± 6.3 a
Mean	228.0 ± 22.7 A	218.2 ± 15.0 AB	215.3 ± 15.4 B	
Dry season				
SSP22	106.6 ± 5.2	133.0 ± 3.1	111.0 ± 7.6	116.9 ± 8.2 a
SSP12	133.1 ± 3.9	138.8 ± 7.1	125.2 ± 4.5	132.4 ± 3.9 a
Mean	119.9 ± 13.3 B	135.9 ± 2.9 A	118.1 ± 7.1 B	

Means followed by different uppercase letters, in the same row, and lowercase letters, in the same column, within the same season, are significantly different by Tukey's test at 5% probability.

Table 8
Accumulation rate (kg ha^{-1} day^{-1}) and cumulative dry mass (kg ha^{-1}) of Piatã grass (mean ± standard error of the mean) in a treeless area (control) and in silvopastoral system with eucalyptus urograndis with spacing between rows at 22 m (SSP22) and 12 m (SSP12) in the rainy and dry seasons.

Treatment	Accumulation rate (kg ha^{-1} day^{-1})[a]		Cumulative dry mass (kg ha^{-1})	
	Rainy season	Dry season[b]	Rainy season	Dry season[a]
Control	64.5 ± 5.7 Aa[c]	15.0 ± 5.7 Ba	11664 ± 1128 Aa	2044 ± 827 Ba
SSP22	31.1 ± 1.9 Ab	10.0 ± 1.0 Ba	5774 ± 309 Ab	1747 ± 101 Ba
SSP12	20.0 ± 2.6 Ab	7.3 ± 0.3 Ba	3796 ± 533 Ab	1186 ± 61 Ba

[a] Forage dry mass accumulation rate.
[b] Dry: was considered, on the basis of soil water balance, the assessment performed under water deficit.
[c] Means followed by different uppercase letters, in the same row, and lowercase letters, in the same column, are significantly different by Tukey's test at 5% probability.

evaluated. This is related to the attempt of the forage to better adapt to low radiation and these changes may have been proportional, both in the leaves and in the stems, not changing its leaf/stem ratio (Gómez et al., 2012).

In environments with less PAR, plants modify their structure (leaf angle, arrangement of leaves in the canopy, etc.) to increase the capture of light over the LAI (Paciullo et al., 2007). This explains the higher LAI values of the SSP22 treatment in the rainy season and also in the center of the spacing between eucalyptus rows when considered the effect of site in both seasons. Shading from 40% reduced the LAI in *B. decumbens* plants in silvopastoral system, according to Bosi et al. (2014).

Under lower incidence of PAR, there is an acclimation in leaf, including fewer supporting tissues and also lower number of mesophyll cells per unit area, which explains thinner leaves (i.e., with greater specific leaf area) (Gómez et al., 2012). This explains our findings regarding the SLA, with higher value in the SSP12, in the rainy season and also in the dry season (compared to control). These results also indicate that the Piatã grass, when in an environment with a lower incidence of solar radiation, seeks to achieve greater solar radiation available use efficiency (Paciullo et al., 2007). While the dry mass of leaves increases linearly with increasing PAR (Fig. 4A), values of PAR use efficiency decline exponentially (Feldhake and Belesky, 2009). Linear relationship between dry matter forage and PAR was also found by Silva-Pando et al. (2002). However, it seems that gains in RUE are only possible under low water stress scenario, as in the rainy season (Fig. 4B).

Table 9
Accumulation rate (kg ha^{-1} day^{-1}) and cumulative dry mass (kg ha^{-1}) of Piatã grass (mean ± standard error of the mean) in silvopastoral system with eucalyptus urograndis with spacing between rows at 22 m (SSP22) and 12 m (SSP12) in the sides West, Center East in relation to the tree row.

Treatment	West	Center	East	Mean
Accumulation rate (kg ha^{-1} day^{-1})				
Rainy season				
SSP22	23.6 ± 3.7	41.8 ± 2.4	28.0 ± 5.7	31.1 ± 5.5 a
SSP12	10.7 ± 3.1	26.9 ± 4.2	22.4 ± 0.8	20.0 ± 4.8 b
Mean	17.1 ± 6.4 B	34.3 ± 7.5 A	25.2 ± 2.8 AB	
Dry season				
SSP22	7.7 ± 1.0	13.7 ± 3.0	8.5 ± 1.4	10.0 ± 1.9 a
SSP12	7.2 ± 0.6	7.2 ± 1.9	7.4 ± 0.9	7.3 ± 0.1 a
Mean	7.4 ± 0.3 A	10.4 ± 3.2 A	8.0 ± 0.5 A	
Cumulative dry mass (kg ha^{-1})				
Rainy season				
SSP22	4393 ± 666	7774 ± 379	5156 ± 1019	5774 ± 1024 a
SSP12	1997 ± 591	5077 ± 808	4314 ± 236	3796 ± 926 b
Mean	3195 ± 1198 B	6426 ± 1349 A	4735 ± 421 AB	
Dry season				
SSP22	1334 ± 297	2224 ± 427	1684 ± 123	1747 ± 259 a
SSP12	1212 ± 217	1050 ± 331	1297 ± 72	1186 ± 72 b
Mean	1273 ± 61 A	1637 ± 587 A	1490 ± 193 A	

Means followed by different uppercase letters, in the same row, and lowercase letters, in the same column, within the same season, are significantly different by Tukey's test at 5% probability.

When there is no water limitation, the plant can trigger mechanisms (changing the structural characteristics) aiming to increase the RUE as a way to offset the impact of shading on available radiation and biomass yield. Under the high water stress scenario, as in the dry season, the water deficit plays a major role than radiation availability (Feldhake and Belesky, 2009) on limiting RUE and biomass accumulation. In fact, under low water availability scenario the plant cannot make up for the loss of available radiation, and at this time, the water restriction is more determining factor for biomass production than the radiation itself. In addition, under water restriction scenario, shading had a negative impact on RUE. Despite the evidence, it is necessary to deepen this research to confirm these hypotheses.

Biomass reduction in the SSP12 treatment was compensated for approximately 33.8% increase in SLA compared with the control in the rainy season and 16.9% increase in the dry season. Gómez et al. (2012) found 45% increase in AFE compensating for the reduction in biomass in *B. decumbens*. Abraham et al. (2014) claimed that, under shading, fewer leaves were kept in the same tiller simultaneously, and presented longer and thinner structures when compared with leaves of plants that have developed in full sun.

Moreover, higher sunlight incidence causes the increase in photosynthetic rate of the plant and hence the accumulation of forage dry mass (Paciullo et al., 2007; Soares et al., 2009; Abraham et al., 2014). Changes in solar radiation interception caused by trees alter the microclimate in the silvopastoral system, and besides that, there is a greater soil moisture removal near the tree row in comparison to the center of the spacing between eucalyptus rows, mainly due to higher exploration of tree roots at greater depths (Pezzopane et al., 2015). These changes may explain the reduction in cumulative dry mass and accumulation rate of Piatã grass in the rainy season in the treatments with eucalyptus in relation to the treeless control. Higher values of accumulation rate and the cumulative forage dry mass in the treeless treatment increased the value of the least significant difference (LSD) in the mean comparison test, and it was not possible to detect significant differences between treatments in silvopastoral systems. When SSP22 and SSP12 were compared, without the treatment control (Table 9), the differences in favor of SSP22 were significant. Wilson and Wild (1990) affirm that most tropical forages decreases production under shading, almost proportionally to the amount of shading, provided that water and nutrients are not limiting factors, corroborating the results found in the present study. Oliveira et al. (2014) also reported a greater dry mass of Piatã grass in treeless area compared to the silvopastoral system. Similar results of reduction in forage dry mass under lower incidence of radiation were also verified by Paciullo et al. (2007), Soares et al. (2009) and Mishra et al. (2010), demonstrating the importance of radiation for tropical forages.

Additionally, when compared to soil water content PAR promotes a greater constraint to forage dry mass production in the absence of water deficit (Burner and Belesky, 2008). In a

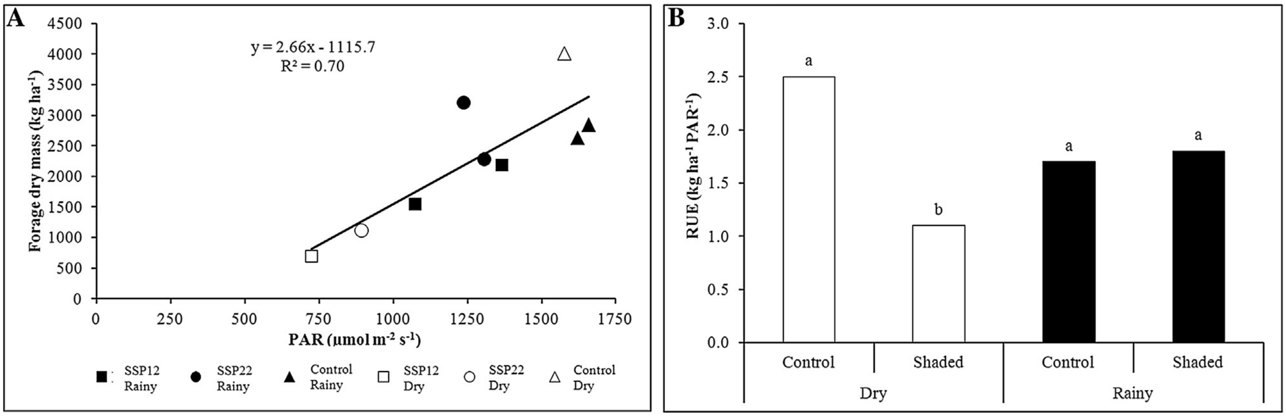

Fig. 4. Forage dry mass and photosynthetically active radiation available (PAR): A—relationship between PAR (μmol m^{-2} s^{-1}) and forage dry mass (kg ha^{-1}); B—radiation use efficiency (RUE) (kg ha^{-1} PAR^{-1})—means followed by different letters, in the same column, are significantly different by Tukey's test at 5% probability.

situation of severe drought experienced by plants for nearly half the year in the Cerrado (Fig. 2), water stress could be more limited to Piatã grass than the reduction of PAR available in this season. This may explain the lack of differences between treatments and sites for forage accumulation rate and cumulative forage dry mass in the dry season.

In relation to the location of the site in the field, the center of the spacing between eucalyptus rows is subjected to less shading than the other areas (Table 1). The reduction of PAR at the center of the spacing between eucalyptus rows, mean of treatments with silvopastoral systems, was 11.4% compared with the control (without trees). This explains the superiority in the cumulative forage dry mass and the forage accumulation rate of the center compared to the West side (PAR reduction of 76%) compared with the control in the rainy season. This reinforces the importance of sampling at different locations throughout the spacing between the eucalyptus rows to estimate the mean cumulative forage dry mass in these systems and consequently insert the proper animal stocking. The filter effect produced by the tree canopy is more intense beside the rows in relation to the center of spacing between rows (Rodrigues et al., 2014). Shading levels above 35% can affect the growth of most tropical grasses (Paciullo et al., 2007). Reductions in green dry mass and forage accumulation were also reported by Paciullo et al. (2011) up to 6 m from the tree row. The absence or reduced competition provided by the eucalyptus at the center of the spacing between rows can also explain the results of higher forage production at that site (Oliveira et al., 2007). In relation to the treatments, the higher cumulative forage dry mass in SSP22 compared with SSP12 was similar to that found by Rodrigues et al. (2014), who explained that a greater spacing between rows allowed high radiation reaching the side of the tree row and also the highest forage dry mass produced in the understory.

The reduction in forage accumulation in silvopastoral systems, as demonstrated in this study, can lead to a lower animal weight gain per hectare compared with the gain in treeless areas (Oliveira et al., 2014). Strategies to help to reduce shading, in order to favor pasture production, can evolve: planting trees in the east-west direction orientation, setting the spacing between rows greater than 22 m and establishing simple lines of trees. In the most advanced stage of the system, pruning and thinning can also be performed to allow more light input to the pasture and to promote the growth of trees. Finally, it is important take into account the income from timber sales in the overall system performance evaluation.

5. Conclusions

The spacing between rows of *Eucalyptus* greater than 22 m is less damaging for pasture productivity when the trees of the silvopastoral system are planted in North–South direction. This contributes for a lower influence on the structural characteristics and higher forage accumulation, especially in the rainy season.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2016.08.026.

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