

Research Paper

Beef cattle production on Piatã grass pastures in silvopastoral systems

Producción de ganado de carne en pasturas de Urochloa brizantha cv. BRS Piatã en sistemas silvopastoriles

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Abstract

Tropical beef cattle production involving animals grazing in a shaded and biologically diverse environment, surrounded by high-quality edible biomass, is achievable through silvopastoral systems (SPSs). However, it is necessary to assess the effects of the presence of trees on forage and animal performance over time. In the Brazilian Cerrado, we evaluated the effects of 2 densities of eucalyptus trees in 2 SPSs (8 years of age - SPS22: 227 trees/ha; SPS14: 357 trees/ha) on forage morphology, production and nutritive value of *Urochloa brizantha* cv. BRS Piatã grass plus performance of Nellore heifers, compared with a grass-only pasture, over a year from 2015 to 2016. On the one hand, SPSs improved ($P < 0.001$) forage nutritive value as reflected in higher crude protein and digestibility and lower neutral and acid detergent fiber concentrations compared with a grass-only pasture. On the other hand, the grass-only pasture had higher ($P < 0.001$) herbage mass and accumulation rate than the SPSs. Forage growth and animal production decreased with higher tree density. Increasing competition from trees with age could be a serious issue limiting pasture and animal production and should be monitored. The suitability of eucalyptus trees for planting in SPSs may be questionable after the 8th year of establishment and further studies are warranted.

Keywords: Agroforestry systems, eucalyptus, grazing systems, ruminant production, shading, tree density.

Resumen

Los sistemas silvopastoriles (SPS) en zonas tropicales permiten la producción de carne con animales en pastoreo en ambientes sombreados y biológicamente diversos. No obstante es necesario evaluar los efectos de la presencia de árboles en la pastura y el rendimiento de los animales a través del tiempo. En el período 2015–2016 se evaluó en el Cerrado brasileño el efecto de dos densidades de eucalipto (*Eucalyptus urograndis*) en dos SPS (SPS22 = 227 árboles/ha; SPS14 = 357 árboles/ha) en algunas características morfológicas, la producción y el valor nutritivo del forraje de *Urochloa brizantha* cv. BRS Piatã, y en el rendimiento de novillas Nellore, en comparación con la pastura sin árboles (Testigo). Los SPS mejoraron ($P < 0.001$) el valor nutritivo del forraje en términos de proteína cruda y digestibilidad más altas, y concentraciones de fibra detergente neutra y ácida más bajas que el Testigo. El Testigo presentó mayor masa de forraje y una mayor tasa de acumulación de este ($P < 0.001$) que los SPS. El crecimiento del forraje y la producción animal disminuyeron con mayor densidad de árboles. El aumento de la competencia de los árboles con la edad podría ser una limitante seria para la producción del pasto y de los animales, y por tanto debe ser monitoreado. La aptitud de los eucaliptos para uso en SPS puede ser cuestionada después del octavo año de establecimiento y necesita mayor investigación.

Palabras clave: Densidad de árboles, producción de rumiantes, sistemas agroforestales, sistemas de pastoreo, sombreado.

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Introduction

Silvopastoral systems (SPSs) are among the most recent agricultural developments in Brazil. Such SPSs provide livestock and forest products from the same area of land in rotation, consortium or succession, over a defined period. The systems have been promoted as a valuable option of sustainable intensification, by increasing food production while maintaining or improving environmental quality and preserving natural biodiversity ([Costa et al. 2018](#)).

The interaction between these components has raised many questions, highlighting the need for further investigations of the benefits of recovering pasture and degraded land, particularly in fragile ecosystems. For instance, livestock are the mainstay of livelihoods, which often leads to pasture degradation due to uncontrolled and poor grazing management practices – as commonly observed in the Brazilian Cerrado ([Peron and Evangelista 2004](#); [Garcia and Ballester 2016](#)).

While tropical forages have high growth rates and good persistence, while enhancing soil cover, they require high incident light to reach maximum levels of production ([Taiz and Zeiger 2010](#)). In SPSs the presence of trees limits the amount of incident light reaching the sward. Dry matter (DM) yields of many tropical grasses and legumes, such as *Urochloa* spp., *Megathyrsus maximus*, *Paspalum notatum*, *Arachis pintoii*, *Neustanthus phaseoloides* (syn. *Pueraria phaseoloides*) and *Stylosanthes* spp., to name but a few, are greatly reduced as shade levels increase compared with sunny environments ([Andrade et al. 2004](#); [Martuscello et al. 2009](#); [Sousa et al. 2010](#); [Araújo et al. 2017](#)). Moreover, in SPSs with eucalyptus and pastures, Pezzopane et al. (2015) observed soil moisture removal near the tree rows was greater than in the inter-row space, which was attributed to increased extraction by tree roots which penetrated to greater depths than the grass.

Nevertheless, several authors have reported an improvement in forage nutritive value under shading, particularly an increase in protein concentration levels ([Baruch and Guenni 2007](#); [Sousa et al. 2010](#); [Paciullo et al. 2016](#)), which enhances animal performance with average daily bodyweight (BW) gains per animal similar to those in sunny environments ([Oliveira et al. 2014](#); [Gamarra et al. 2017](#)).

Amongst tropical forage grasses, the Piatã cultivar (*Urochloa brizantha* cv. BRS Piatã), adapted to medium fertility and well-drained soils, has been considered by researchers as a suitable option for planting in SPSs ([Gamarra et al. 2017](#); [Geremia et al. 2018](#)). It is also an alternative for pasture diversification, showing high

herbage mass production in Brazilian Cerrado soils ([Euclides et al. 2008](#)).

One of the grazing management practices used in sunny environments under continuous stocking is based on predetermined canopy heights ([Martuscello et al. 2009](#); [Pontes et al. 2016](#)). However, there have been few recommendations for grazing management under shading ([Baldissera et al. 2016](#)).

As mentioned above, despite promoting a series of benefits, the presence of trees in pastures might decrease herbage mass and soil cover, along with reduction in soil moisture, and hence, constrain animal production over time – due to the continuous growth of trees with increased competition for light, water and nutrients. Therefore, the spatial arrangement of tree rows should match the intended objective, whether emphasis be on forest or livestock production. Long-term studies are required to avoid a decline in forage and animal production ([Paciullo et al. 2011](#)).

The systems evaluated in the present study were planted in 2008, aiming at recovering a degraded pasture. The 2 tree arrangements were designed to favor livestock production instead of forest production, following the majority of systems assembled at that time, with a short distance between the tree rows ([Andrade et al. 2008](#); [Devkota et al. 2009](#); [Paciullo et al. 2008, 2011](#)).

We hypothesize that herbage mass and animal growth rates are likely to decrease with time due to shading and other competitive effects in silvopastoral systems with eucalyptus trees, whereas in systems with lower eucalyptus tree density, BW gains per animal and per ha could be similar to those in a grass-only pasture as a result of improved forage nutritive value. Since the systems under study were in their 8th year since establishment, we measured pasture yield and quality plus animal performance at 2 densities of trees in comparison with a grass-only pasture.

Materials and Methods

Study site

Establishment of the experimental area was previously described in detail by Pereira et al. (2014). The experiment was carried out at Embrapa Beef Cattle, located in Campo Grande, Mato Grosso do Sul state, Brazil (20°27' S, 54°37' W; 530 masl), from June 2015 to May 2016. All procedures were approved by the Ethics and Animal Use Commission of Embrapa Beef Cattle under protocol no. 014/2014. According to the Köppen classification, climate of the experimental area falls in the transition between Cfa and humid tropical Aw, with

average annual rainfall of 1,560 mm. The dry season occurs in the coldest months (May–September) and the rainy season in the hottest months (October–April). Air ambient temperature and precipitation data during the trial were collected from Embrapa Beef Cattle meteorological station, and along with mean rainfall data for the last 30 years for the Campo Grande region from the National Institute of Meteorology (A756 – INMET), are depicted in Figure 1.

The soil at the experimental site was a Dystrophic Red Latosol, with clay texture, characterized by low pH, low base saturation and medium aluminum concentration. Mean values from soil chemical analyses performed in 2013 in the 0–20 cm layer showed that the area was relatively uniform, with clay contents of $41 \pm 5\%$; P (Mehlich-1) 0.29–0.42 mg/dm³; base saturation 26–34%; and aluminum saturation 10–23%.

In August 2008, soil preparation was performed through a heavy disking, subsoiling and applications of 3,000 kg lime/ha, 1,000 kg gypsum/ha and 300 kg fertilizer/ha as N:P:K (5:25:15) broadcast over the pasture canopy, followed by leveling with disk harrows. The 18-ha experimental area was divided into 12 paddocks each of 1.4 ha with 4 paddocks (experimental units) for each system evaluated. Three systems were established: grass-

only system without trees, representing the Control treatment (CON); and 2 silvopastoral systems with eucalyptus trees, i.e. SPS22 with an arrangement of 22 m spacing between tree rows \times 2 m tree spacing within rows, totaling 227 eucalyptus trees/ha; and SPS14 with an arrangement of 14 \times 2 m, totaling 357 eucalyptus trees/ha. *Eucalyptus urograndis* clone (*E. urophylla* \times *E. grandis*) was planted in single lines oriented at -20.41° south and -54.71° west in relation to the east-west axis. All systems followed the same management, involving a crop rotation strategy every 4 years, i.e. cultivation of soybean as a crop for one year, followed by 3 years with solely *Urochloa brizantha* cv. BRS Piatã grass.

The present experiment was carried out in the third year after pasture establishment in the second rotation cycle. In January 2016, the pasture received maintenance fertilizer of 50 kg N/ha, in the form of urea, plus 300 kg N:P:K fertilizer/ha (0:20:20).

The eucalyptus trees had reached average heights of 27 and 25 m in the SPS14 and SPS22 systems, respectively. In order to characterize the level of luminosity reaching the Piatã grass canopy, the photosynthetically active radiation (PAR) was recorded at canopy height at 5 points in each SPS paddock, and at a point under full sun conditions immediately before and at the end of SPS

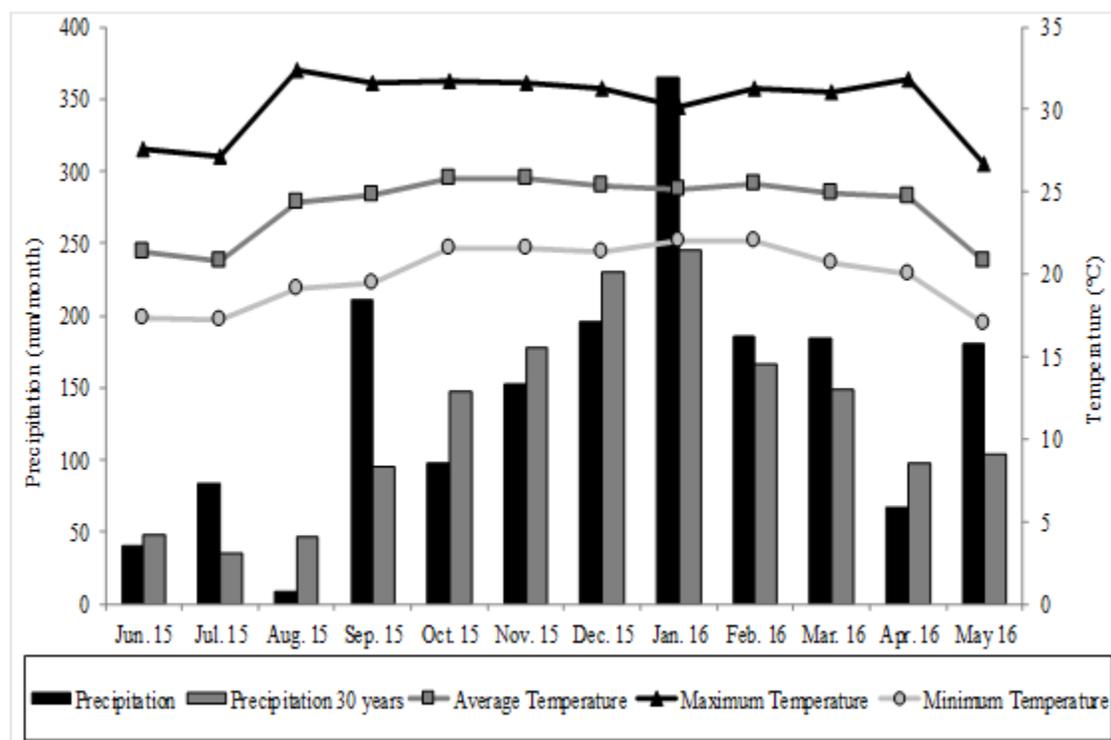


Figure 1. Maximum, average and minimum air ambient temperatures and precipitation from June 2015 to May 2016, and mean rainfall data for the last 30 years for the Campo Grande region, Mato Grosso do Sul. Winter: June–August; spring: September–November; summer: December–February; autumn: March–May.

recordings. All readings were taken in the morning and afternoon on one sunny day each month using a plant canopy analyzer (Accupar Ceptometer Model LP-80, METER Group Inc., Pullman, USA). Means of PAR were used to calculate the percentage of shading at grass canopy level in the SPS14 and SPS22 for each month, as a ratio between PAR reaching the canopy at the sampling points and PAR under full sun conditions at the corresponding measurement time.

The experimental design utilized was a randomized block (3 systems with 4 replications). The pastures were continuously grazed, with stocking rates (SR) intentionally varied over time to achieve predetermined pasture heights, according to Mott and Lucas (1952). For autumn and winter, height ranged from 30 to 35 cm, and for spring and summer from 35 to 40 cm.

Measurements of forage and animal parameters

A total of 80 Nellore (*Bos indicus*) heifers (initial mean body weight, BW = 290.8 ± 26.1 kg, ± SD) were randomly allocated to the paddocks and an extra area for SR management. Heifers had ad libitum access to water and a commercial mineral supplement, which was replenished weekly on the basis of 140 g/animal/d, and unrestricted access to their particular pasture area. Animals were weighed every 28 days in the morning, on a weigh scale (MRG Campo, Toledo, São Bernardo do Campo, Brazil; precision of 0.5 kg), following a 16 h fast from feed but with access to water. All heifers were vaccinated according to the official health calendar and dewormed at the beginning of the experiment. Overgrazing of SPS14 paddocks occurred in winter and animals were removed on 23 June 2015 and were returned to the paddocks on 9 December 2015. A similar situation occurred on SPS22 in spring and stock were removed on 15 September 2015 and were returned on 9 December 2015.

Average daily BW gain (ADG) was calculated by dividing the difference between the initial and final BW of animals by the number of days between weighings. Monthly SR (animal unit, AU = 450 kg) was the product of average BW and the period for which the animals remained on the paddocks. Animal BW gain per hectare (AWG) was calculated by multiplying ADG by the number of animals per hectare per month.

Canopy height measurements were taken from ground level to the top surface of the pasture leaf canopy, using a 1-m rule graduated in cm, every 2 weeks at 50 random points per paddock. Forage sampling was performed every 28 days, along 2 transects sited at right angles between the tree rows; along each transect, samples were

taken at 5 points defined as 1 m from the north tree row, 1 m from the south tree row, 6 m from the north tree row, 6 m from the south tree row, and at the central point between the tree rows, 11 m from each row, in SPS22 (Figure 2). For SPS14, sites were 1 m from the north tree row, 1 m from the south tree row, 3 m from the north tree row, 3 m from the south tree row, and at the central point between the tree rows, 7 m from each. In CON, the points were chosen at random. Ten samples per paddock were harvested at 0.4 m from ground level using a coastal harvester, within a metallic frame of 1 × 1 m. Conjointly, forage accumulation was measured using the exclusion cage technique, according to Davies (1993) and Stuth et al. (1981), by placing 5 cages of 1 × 1 m per paddock along the canopy height transects between the tree rows, following the same procedure as used for the sampling points described above. The exclusion cages were moved to a new location every 28 days, and comparable points were always harvested to simulate the growth of the pasture.

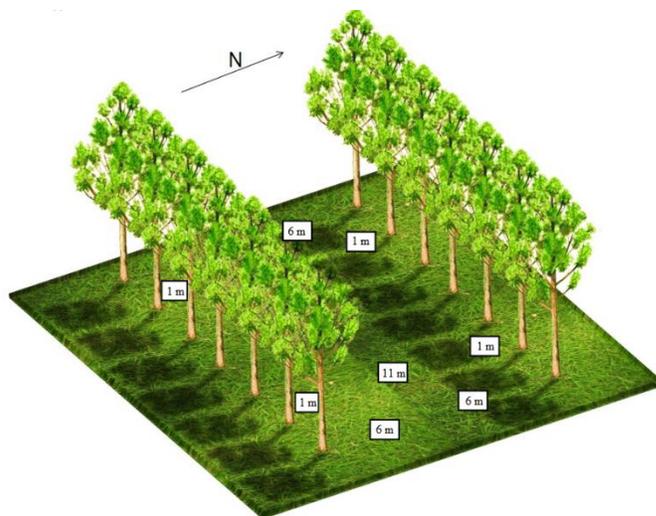


Figure 2. Schematic representation of forage sampling points along 2 transects sited at right angles to the eucalyptus rows in a silvopastoral system (SPS22: grass + 227 trees/ha). The distance separating each point from the trees rows is represented by the boxes. (Adapted from Oliveira et al. 2019).

All forage samples collected were individually weighed after harvesting. For each harvest, subsamples for each sampling point, for instance, along each transect, and from inside and outside the cages, were separately pooled and taken, put into paper bags, and dried in a forced-air oven at 65 °C until constant mass for determination of dry matter (DM). Another subsample from each sampling point was selected and separated into its morphological components – leaf blade, stem with sheath and senescent material. Likewise, the morpho-

logical components were weighed and subsequently dried in a forced-air oven at 65 °C for DM determination. Herbage mass (HM) was the average of measurements from all sampling points. The morphological component proportions were calculated as percentage of the total HM. Herbage accumulation rate (HAR) was the difference between the HM within the cages and outside the cages at previous harvest, i.e. when the cage was repositioned, divided by the days between samplings.

Canopy bulk density was calculated by dividing HM by canopy height at the sampling point where HM was measured. To determine herbage allowance (HAL, kg DM/100 kg BW), HM was summed up to the HAR, and divided by the SR transformed in kg BW in the area and season.

Dried leaf and stem samples were ground in a Wiley mill to pass a 1-mm screen. Crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations and in vitro digestibility of organic matter (IVDOM) were assessed through the proximal infrared reflectance spectrophotometry system (NIRS) according to Marten et al. (1985). Forage nutritive value was measured monthly and means determined seasonally. However, it was not possible to assess the chemical composition in autumn.

Statistical analysis

Data were grouped by season as follows: winter, results for June to August 2015 inclusive; spring, for September to November 2015; summer, for December 2015 to February 2016; and autumn, for March to May 2016. Data were analyzed by PROC GLM procedure through SAS V9.4 program (SAS Institute Inc., Cary, NC, USA), with a model including effects of block, system, season and their interactions. Means were compared using LSMEANS by Tukey test, and considered different when $P < 0.05$.

Results

The PAR levels reaching the sward in CON, SPS22 and SPS14 are depicted in Figure 3, which shows that the amount of light reaching the grass canopy was highest in spring and declined as tree density increased. Amount of incident light reaching the grass canopy in SPS14 in winter, summer and autumn was 16–22% of that in full sun, while in spring 44% of light penetrated the trees. In SPS22, 45–50% of light reached the pasture throughout the year. There was an interaction of system \times season ($P < 0.01$) for pasture canopy height, HM, leaf and stem proportion and

leaf:stem ratio. Canopy height in CON was taller ($P < 0.001$) than in SPS14 in winter, whereas in spring, when both SPSs were destocked, canopy height in CON was shorter ($P < 0.001$) than in both systems with trees, SPS22 and SPS14 (Table 1). In CON, HM was greater ($P < 0.001$) than in both systems with trees for all seasons (Table 1). However, HM did not differ ($P > 0.05$) between the systems with trees, despite the amount of PAR reaching the canopy in SPS14 being little more than half of that in SPS22.

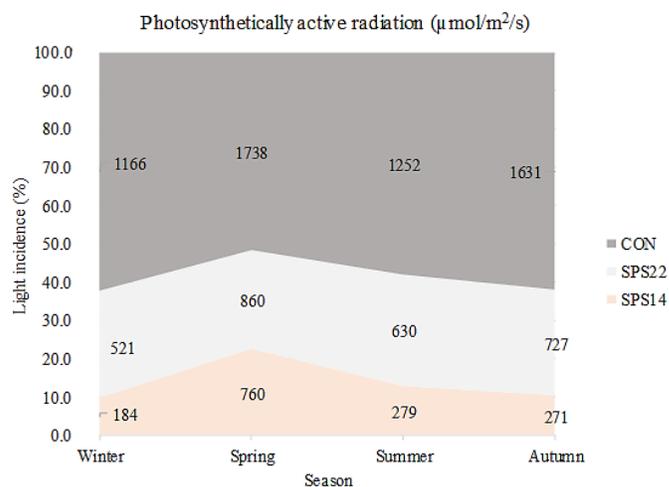


Figure 3. Light incidence reaching the sward in the silvopastoral systems (CON: grass-only, SPS22: grass + 227 trees/ha, SPS14: grass + 357 trees/ha), in the different seasons.

During winter, summer and autumn, leaf proportion in available forage was similar ($P > 0.05$) in all systems (Table 1). In spring, when the SPSs were destocked, leaf proportion in available forage was higher in SPS22 and SPS14 than in CON ($P < 0.001$; Table 1). In all systems, leaf proportion in available forage in spring and summer was greater than in winter and autumn. Similarly, summer had the highest stem proportion in available forage for all systems ($P < 0.001$). Leaf:stem ratio in available forage was highest in spring ($P < 0.001$) for all systems. Differences between systems were inconsistent, with no differences observed between systems in winter and summer ($P > 0.05$), while significant differences occurred in spring and autumn ($P < 0.001$).

Regarding forage nutritive value of leaf and stem, CP, NDF, ADF and IVDOM were affected ($P < 0.01$) by a system \times season interaction. Leaf CP varied from 84 to 145 g/kg DM across systems and seasons, with SPS14 and SPS22 having higher leaf CP than CON ($P < 0.001$; Table 2). Leaf CP was generally higher in winter than in summer. Similarly, stem CP ranged from 45 to 104 g/kg DM with higher values for SPS14 and SPS22 than for CON ($P < 0.001$) and higher values in spring than in winter and summer ($P < 0.001$).

Table 2. Nutritive value of Piatã grass leaf and stem in the systems CON, SPS22 and SPS14 during different seasons.

Season (S)	System (T)			s.e.m.	P-value	
	CON	SPS22	SPS14		T	T × S
Leaf						
Crude protein concentration (g/kg DM)						
Winter	110Ab	132Aa	137Aa ¹	0.38	<0.001	0.001
Spring	97ABc	123ABb ¹	145Aa ¹			
Summer	84Bb	118Ba	131Aa			
Neutral detergent fiber concentration (g/kg DM)						
Winter	686Aa	682Aa	687Aa ¹	1.01	<0.001	0.004
Spring	693Aa	689Aa ¹	651Bb ¹			
Summer	697Aa	676Ab	642Bc			
Acid detergent fiber concentration (g/kg DM)						
Winter	306Ba	292Ba	306Aa ¹	0.6	0.007	0.001
Spring	313ABab	321Aba ¹	290Ab ¹			
Summer	339Aa	323Ab	309Ab			
In vitro organic matter digestibility (g/kg DM)						
Winter	642Ab	682Aab	696Ba ¹	2.26	<0.001	0.004
Spring	629Ac	699Ab ¹	757Aa ¹			
Summer	579Bc	625Bb	684Ba			
Stem						
Crude protein concentration (g/kg DM)						
Winter	48Bb	60Ba	67Ba ¹	0.26	<0.001	<0.001
Spring	63Ab	96Aa ¹	104Aa ¹			
Summer	45Bc	55Bb	65Ba			
Neutral detergent fiber concentration (g/kg DM)						
Winter	766Aa	771Aa	767Aa ¹	0.7	<0.001	0.004
Spring	758Aa	729Bb ¹	714Bb ¹			
Summer	771Aa	775Aa	743Ab			
In vitro organic matter digestibility (g/kg DM)						
Winter	478Ba	489Ba	485Ba ¹	2.91	0.002	0.001
Spring	557Ab	618Aa ¹	659Aa ¹			
Summer	490Ba	464Ba	493Ba			

Means followed by the same upper-case letter within columns and parameters and lower-case letters within rows do not differ ($P>0.05$) by the Tukey test. CON: grass only, SPS22: grass + 227 trees/ha, SPS14: grass + 357 trees/ha. ¹Pastures destocked.

Table 3. Canopy bulk density, herbage accumulation rate (HAR) and herbage allowance (HAL) in the systems CON, SPS22 and SPS14 during different seasons.

Season (S)	System (T)			s.e.m.	P-value	
	CON	SPS22	SPS14		T	T × S
Canopy density (kg DM/m ³)						
Winter	0.52Ba	0.23Cb	0.20ABb ¹	0.02	<0.001	0.032
Spring	0.60Ba	0.28BCb ¹	0.14Bb ¹			
Summer	1.12Aa	0.56Ab	0.42Ab			
Autumn	1.00Aa	0.51ABb	0.35ABb			
HAR (kg DM/ha/d)						
Winter	6.9Ba	-15.8Ba	-11.0Ba	0.92	<0.001	0.01
Spring	51.7Aa	48.4Aa	33.4Aa			
Summer	63.1Aa	16.8Bb	3.9Bb			
Autumn	62.8Aa	13.9Bb	-1.4Bb			
HAL (kg DM/100 kg BW/d)						
Winter	4.49Ca	2.23Ba	D ¹	0.99	<0.001	0.22
Spring	8.64AB	D	D			
Summer	11.22Aa	7.94Aa	8.25Aa			
Autumn	4.85BCa	3.93Ba	1.19Ba			

Means followed by the same upper-case letter within columns and parameters and lower-case letters within rows do not differ ($P>0.05$) by the Tukey test. CON: grass only, SPS22: grass + 227 trees/ha, SPS14: grass + 357 trees/ha. ¹SPS14 was destocked in winter and spring and SPS22 was destocked in spring.

Table 4. Stocking rate (SR), average daily BW gain (ADG) and animal BW gain per hectare (AWG) in the systems CON, SPS22 and SPS14 during different seasons.

Season (S)	System (T)			s.e.m.	P-value	
	CON	SPS22	SPS14		T	T × S
		SR (AU/ha)		0.3	<0.001	0.09
Winter	1.3Aa	0.7Aa	D ¹			
Spring	1.1A	D	D			
Summer	2.6Aa	2.4Aab	1.5Ab			
Autumn	2.6Aa	1.2Ab	0.9Ab			
		ADG (kg BW/animal/d)				
Winter	0.160Ba	0.058Ba	D	0.13	<0.001	<0.001
Spring	0.525A	D	D			
Summer	0.588Aa	0.783Aa	0.648Aa			
Autumn	0.373ABa	0.238Ba	0.435Aa			
		AWG (kg BW/ha)				
Winter	17Ba	3Ba	D	19.78	<0.001	<0.001
Spring	54Ba	D	D			
Summer	169Aa	186Aa	93Ab			
Autumn	136Aa	39Bb	25Bb			

Means followed by the same upper-case letter within columns and parameters and lower-case letters within rows do not differ ($P > 0.05$) by the Tukey test. AU = 450 kg BW. CON: grass only, SPS22: grass + 227 trees/ha, SPS14: grass + 357 trees/ha. ¹D = destocked. BW = Body weight.

Discussion

This study has shown the huge impact of established eucalyptus trees on pasture growth in a silvopastoral system. During summer and autumn, when pastures in full sunlight (CON) grew at 63 kg DM/ha/d, those in SPSs grew at 15 (SPS22) and 1 (SPS14) kg DM/ha/d. Reductions in growth of this magnitude must raise the issue of the suitability of eucalyptus for planting in these silvopastoral systems. Not only do they produce shade but also have a well-developed root system which competes strongly for moisture (Ferraz et al. 2019; Mattos et al. 2019) and nutrients in the soil.

The systems with trees, SPS22 and SPS14, are likely to be more negatively affected by the winter season than CON. During water stress conditions, as in the winter, plants cannot compensate for the limited PAR by triggering mechanisms to increase radiation use efficiency. Leaf stomata must open to allow carbon dioxide diffusion into the leaf to utilize PAR. However, during water shortage, leaf stomata close or partially close to reduce water loss, which hampers carbon dioxide uptake (Feldhake 2009). This would result in negative HAR for SPS22 and SPS14 in winter, low canopy height, HM, leaf and stem proportions, canopy density and consequently limited animal production. During this season, only a few heifers continued to graze in SPS22 due to the canopy height, even though canopy height might not be an appropriate criterion for determining when to graze SPSs.

Canopy height is a grazing management target applied in grazing systems in the tropics, as it is highly correlated with HM (Martuscello et al. 2009; Pontes et al. 2016). Nantes et al. (2013) and Euclides et al. (2016) recommended a canopy height within the range 15–45 cm for Piatã grass under continuous stocking in full sun. Our findings suggest that canopy height is not an appropriate criterion for grazing management in shaded environments, because of large oscillations in the amounts of available biomass despite having a similar height, as a result of different structure of pasture in shade. Pontes et al. (2016) also reported an over-grazing condition in cool-season pastures under trees, showing low HM under >50% shade, when the systems were managed using a canopy height target defined for full-sun conditions.

It has been reported that shading imposed on forage grasses increases canopy height by stem and leaf elongation and leaf length enlargement, as a mechanism to improve light capture by the plant. The higher stem proportion in SPS14 during spring and summer, where incident light was severely restricted, supports this hypothesis. In contrast, tiller density declines at low radiation, which in turn decreases available HM (Castro et al. 2009; Gastal and Lemaire 2015; Baldissera et al. 2016).

Even though SPS22 and SPS14 had a taller pasture canopy than CON in the spring, their low HM (1,032 and 642 kg DM/ha for SPS22 and SPS14, respectively) was insufficient to support animals grazing during this season. Hodgson (1990) indicated a minimum HM of 2,000 kg

DM/ha to avoid restricting forage intake. Critically, HM in SPS22 surpassed this threshold only in summer, whereas SPS14 barely achieved it in summer, regardless of the absence of animals in winter and spring. Animals were returned to SPS14 in summer based on HAL of 8 kg DM/100 kg BW, as a result of the onset of rains in September coupled with an increase in PAR and the absence of animals in spring.

The HAR in CON in the winter is in good agreement with 6.0 kg DM/ha/d of Piatã grass growing in a full-sun condition, reported by Euclides et al. (2016) in the dry season, which occurs in winter. Subsequently, rainfall in September boosted HAR in spring for all systems, and HAR in CON closely matched the 64.1 kg DM/ha/d reported by Euclides et al. (2016) and the 64.5 kg DM/ha/d by Santos et al. (2016) during the rainy season. Rather than grouping data by winter, spring, summer and autumn, those authors grouped their data according to rainy and dry seasons. Santos et al. (2016) also evaluated HAR of Piatã grass in systems with eucalyptus trees. Despite having low values ranging from 20.0 to 31.1 kg DM/ha/d in the rainy season and 7.3 to 10.0 kg DM/ha/d in the dry season, the HAR was not negative as found in our study. Those authors affirmed that PAR declined by approximately 22 and 40% for their systems with lower and higher tree density, respectively, whereas PAR in our study declined on average by 53 and 75% for SPS22 and SPS14, respectively. Additionally, minimum air temperature from May to July reached 17 °C, the threshold for the growth of the pasture, as the temperature base for *Brachiaria brizantha* is 17.2 °C, the temperature at which HAR is zero (Cruz et al. 2011).

The HAR in SPS22 and SPS14 in summer declined dramatically, whereas in CON it increased by about 25%. Competition for nutrients and incident radiation by trees obviously prevented grass from accumulating forage at a greater rate, highlighting the effects of radiation on the growth of tropical grasses of C₄ metabolism (Taiz and Zeiger 2010).

The PAR in summer for all systems was considerably lower than in spring, with levels in SPS14 being quite low. Since PAR declined dramatically in the CON system as well as SPSs, cloud cover may have contributed to reduced levels of incident light overall, and change in sun position relative to the configuration of the trees possibly had a significant impact on the amount of light reaching the grass canopy in the SPSs.

Regardless of the lack of statistical differences for HM and HAR between SPS22 and SPS14 throughout the study, SPS22 constantly showed higher absolute values than SPS14, which ensured animals were retained in SPS22 during winter.

A morphological change influenced by shading is leaf elongation, which in turn increases leaf proportion (Baldissera et al. 2016). However, the general preference for leaves by animals could limit leaf accumulation in the forage canopy of the systems with trees. Due to low HM in both SPS22 and SPS14, removal of leaves by the animals would be expected to be more pronounced in those systems than in CON, despite the fact that HALs on all systems showed no significant difference. The only period when SPS22 and SPS14 had higher leaf proportion than CON was in spring, when the systems with trees were destocked. Animals preferentially select leaf when grazing forage, resulting in increased animal performance due to its highest nutrient concentrations (Geremia et al. 2018).

As expected, forage nutritive value in SPSs was superior to that in CON, mainly with regard to higher CP in shaded environments (Paciullo et al. 2016; Lima et al. 2018). Even though reports in the literature for effects of shading on NDF, ADF and IVDOM are inconsistent, several authors have recorded reductions in NDF (Paciullo et al. 2008, 2016; Lima et al. 2018) and ADF (Lima et al. 2018) in shade, which was attributed to higher numbers of sclerenchyma cells and thicker secondary walls under greater light incidence (Kephart and Buxton 1993; Deinum et al. 1996). A delay in morphological maturation within shaded environments compared with full sun conditions has also been claimed (Neel et al. 2016).

Despite the lower HM and higher stem proportion in SPS22 and SPS14, ADGs of animals in all systems were similar during summer and autumn, when HAL in all systems was similar. Systems with trees also had a higher forage nutritive value in summer than the grass-only system. However, as a consequence of lower SR in SPS14, its AWG was lower than that in CON and SPS22. Likewise, SPS22 provided lower AWG than CON in autumn due to a drop in SR.

Studies carried out in the area in previous years allowed grazing in all the systems during the whole experimental period (Oliveira et al. 2014; Gamarra et al. 2017). Moreover, in the third year after pasture establishment for the first rotation cycle (2011–2012), CON produced 537 kg BW/ha/yr, SPS22 459 kg BW/ha/yr and SPS14 334 kg BW/ha/yr (Oliveira et al. 2014). In the corresponding period of the second cycle in our study (2015–2016), BW production was appreciably lower, i.e. 376 kg BW/ha/yr, 228 kg BW/ha/yr and 118 kg BW/ha/yr in CON, SPS22 and SPS14, respectively. While a range of factors could have contributed to this reduction in animal production, continuous tree growth could have had an important impact, especially in the

SPSs. Eucalyptus trees may have a root system which spreads out a horizontal distance about 20 m from the trunk of individual trees (Zohar 1985). Tree root zone as a sink removes water arriving at the soil surface within the radius of its root zone, influencing the soil water movement and availability (Stirzaker et al. 1999; Bosi et al. 2019). Since these trees were 8 years old and were 25–27 m tall at the commencement of the study, and plot size was 1.4 ha, competition for water and nutrients in the grass-only pasture from adjacent trees cannot be dismissed. Eucalypts are very competitive with underlying pasture, and it is important that the changes in the degree of competition with underlying crops and pastures be monitored throughout the whole tree growing cycle, as proposed by Gomes et al. (2019).

For CON, the decline in animal production in the second cycle could reasonably be attributed to stocking management. Oliveira et al. (2014) observed higher AWG and SR in short swards managed at 27 ± 4.6 cm, whereas in the current study, the sward height of CON ranged from 31 to 46 cm across the seasons. Our results for winter and spring differed only slightly from those reported by Oliveira et al. (2014), the seasons where the authors found no differences for AWG according to the height managed. It seems that CON could be grazed at different heights from SPSs. We conclude that pasture height should not be the sole criterion on which appropriate stocking rate for grazing pastures under trees is assessed. Further studies are warranted to determine a more appropriate criterion for deciding when and how to graze these pastures.

Conclusions

Silvopastoral systems with eucalyptus trees like those studied are unable to support both forage and animal production equivalent to a straight grass pasture by the 8th year after establishment. Further studies are needed to determine appropriate management of the trees to reduce competition for the pasture. One might question the suitability of eucalypts for these silvopastoral systems because of their high levels of competition for water, light and nutrients. Pruning and thinning of the trees have been implemented in an endeavor to reduce competition and these practices have been recommended in the literature (Santos et al. 2016; Lima et al. 2018; Pezzopane et al. 2019, 2020) to reduce radiation interception starting from the 6th to 8th year after establishment. However, eucalyptus trees retain a competitive advantage over pasture even after thinning and tree stands recover rapidly and increase their competition with pasture (Back et al. 2009). Studies to evaluate those interactions between pasture and trees seem warranted.

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Statement of Animal Rights

All procedures were approved by the Ethics and Animal Use Commission of Embrapa Beef Cattle under protocol nº 014/2014.

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