Received: 1 February 2018 | Revised: 1 September 2018 | Accepted: 3 October 2018
DOI: 10.1111/gfs.12395

ORIGINAL ARTICLE

WILEY Grass and Forage Science

Productivity and nutritive value of *Brachiaria decumbens* and performance of dairy heifers in a long-term silvopastoral system

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Funding information
Fundação de Amparo à Pesquisa do Estado de Minas gerais (FAPEMIG); Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq); Instituto Nacional de Ciência e Tecnologia -Ciência Animal (INCT -CA); Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)

Abstract

Silvopastoral system (SPS) has been suggested to ensure sustainability in animal production systems in tropical ecosystems. The objective of this study was to evaluate the productive and nutritive value traits of *Brachiaria decumbens* and performance of dairy heifers in SPS and open pasture (OP) during the summer and autumn of two consecutive years in the SPS and OP (17th and 18th years after establishment). Experimental design was a randomized complete block with two treatments (SPS and OP) and three replications in subdivided plots with repeated measures in time. There was reduction in the tiller population density, total and green forage mass, and total and green forage bulk density in the SPS when compared to the OP in the summer. In the autumn, no difference was observed between the systems. Shading in SPS increased crude protein content of the grass pasture by 25% and 33% when compared to the OP during the first and second experimental years, respectively, and reduced neutral detergent fibre content. However, it did not change acid detergent fibre or lignin content. OP provided higher stocking rate and weight gain per area than the SPS. Average daily gain was higher in the OP in the second experimental year. Severe shading conditions should be avoided, because in the long-term they may threaten the persistence and sustainability of pasture in the SPS. It is recommended to plant a low density of trees or implement management strategies of the tree component by either thinning or pruning over the years after planting.

KEYWORDS
dairy heifer, forage production, forage quality, shading, sustainability

1 | INTRODUCTION

The demand for sustainable livestock systems that promote improvements in environmental, social and economic services has increased, and the adoption of integrated systems is a promising alternative to recover degraded areas, especially in mountainous regions. Paciullo et al. (2017) have suggested that an option for sustainable livestock production is the adoption of silvopastoral system (SPS). Among the productive and environmental benefits of the SPS, the following stand out: Improved soil nutrient availability, increased animal production associated with thermal comfort, and higher crude protein (CP) content of forage, as well as the possibility of income diversification in the property (Baliscei et al., 2013; Kyriazopoulos, Abraham, Parissi, Koukoura, & Nastis, 2013; Murgueitio, Calle, Uribe, Calle, & Solorio, 2011; Paciullo et al., 2011), and environmental services, such as increased biodiversity, sequestration of atmospheric carbon and mitigation of greenhouse gases (Alves, Madari, & Boddey, 2017; López-Carrasco, López-Sánchez, San Miguel, & Roig, 2015).

Among the species of tropical grasses of the C_4 photosynthetic pathway that have medium tolerance to shading, some *Brachiaria* and *Panicum* cultivars stand out, with at *Brachiaria decumbens* being considered one of the most adapted for SPS, especially those established in regions with a mountainous topography (Gobbi et al., 2009). However, pasture management in SPS is more complex when compared to an open pasture (OP). One of the main limitations in SPS is the decrease in the amount (i.e., photon flux density) and the quality (e.g., changes in the red: far red) of the photosynthetically active radiation (PAR) incident on the forage canopy with the age of the trees, which can reduce tillering and forage production and alter nutritive value (Abraham et al., 2014; Barnes et al., 2015; Neel & Belesky, 2017).

In this sense, long-term evaluations in SPS are fundamental for a better understanding of the potential of the system in subsequent years. This study represents a contribution to long-term animal husbandry assessments in SPS. A better understanding of the productive responses of each component of the system, over time, offers opportunities for proposing intervention measures and management adjustments that guarantee productive, economic and sustainable stability of the system. This is the gap in the literature, while there are many evaluations carried out in the early years of establishment, few studies evaluate for a longer period of time, which is undoubtedly a very short time to draw conclusions regarding the persistence and sustainability of the system.

We hypothesized that the long-term SPS could increase the individual weight gain of dairy heifers in relation to OP, due to the higher CP content and more comfortable environment for animals. However, more intense shading in SPS could negatively affect pasture productivity, leading to a lower stocking rate and animal production per area. In this regard, the objective of this study was to evaluate the productive and nutritive value traits of *Brachiaria decumbens* and performance of dairy heifers in SPS and OP during the summer and autumn of two consecutive years, which characterized the systems in the 17th and 18th years after establishment.

2 | MATERIALS AND METHODS

2.1 | Experimental site and systems history

The study was performed at the Embrapa Dairy Cattle (EMBRAPA—Brazilian Agricultural Research Corporation) in the city of Coronel Pacheco, Minas Gerais, Brazil, in a SPS and OP in an area of mountainous topography, with a slope of approximately 30% (21°33′22′′S, 43°06′16′′W, 410 m a.s.l.) and 8.4 ha. Experimental period spanned the summer and autumn of two consecutive years, 2014/2015 and 2015/2016.

The climate data were collected at the automatic meteorological station located 500 m from the experimental area (Figure 1). The climate of the region, according to Köppen's classification, fits the Cwa type (mesothermal), with a well-defined dry season (autumn–winter) and rainy season (spring–summer). The soil in study area is of the red–yellow latosol type and is dystrophic with a clayey texture and mountainous topography (Embrapa, 2013). Soil sampling was performed at 0–20 cm depth in the SPS and in the OP for soil chemical characterization. Average soil chemical analyses in the SPS and OP were, respectively, as follows: pH (water), 4.7 and 4.7; phosphorus (Mehlich-1), 3.7 and 1.9 mg/dm^3; potassium, 50.6 and 49.5 mg/dm^3; calcium, 0.9 and 0.7 cmolc/dm^3; magnesium, 0.4 and 0.3 cmolc/dm^3; aluminium, 0.9 and 0.7 cmolc/dm^3; H + Al, 6.0 and 5.4 cmolc/dm^3; and organic matter, 3.8 and 3.8 dag/kg.

The experimental area, where this study was carried out, has been used in multidisciplinary studies since its establishment in November 1997 (Müller, Fernandes, de Castro, Paciullo, & Alves, 2010; Paciullo et al., 2010; Xavier et al., 2014). The SPS is structured in 30-m-wide strips with the tropical perennial grass *Brachiaria decumbens* syn. *Urochloa decumbens* Stapf. cv. Basilisk and alternated with 10-m tree rows. The tree component was composed with the species *Eucalyptus grandis*, besides the tree legumes *Acacia mangium* and *Mimosa artemisiana* establishment planted in the North–South direction, aiming to prevent surface erosion, arranged with four rows of trees spaced 3 × 3 m between trees. The OP was established with the *B. decumbens* in full sun. The tree legumes were used to provide shade and biomass rich in nitrogen and other nutrients, and eucalyptus was used to provide shade and wood production. The tree species were planted alternately in the planting lines. Before planting of the tree species, 1,000 kg/ha of dolomitic limestone, 600 kg/ha of natural phosphate, 250 kg/ha of single superphosphate, 100 kg/ha of potassium chloride and 30 kg/ha of micronutrients (FTE BR-16) were added. Fertilization for the planting of the *A. mangium* and *M. artemisiana* seedlings was performed with the application of 50 g of dolomitic limestone, 80 g of natural phosphate, 100 g of single superphosphate, 25 g of potassium chloride and 10 g of FTE BR-16 per well; fertilization for the *E. grandis* species was performed with the application of 75 g of ammonium sulphate, 225 g of single superphosphate and 15 g of potassium chloride. For the establishment of the OP, the soil preparation protocol was followed, and the application of correctives and fertilizers was similar to that used in the SPS.

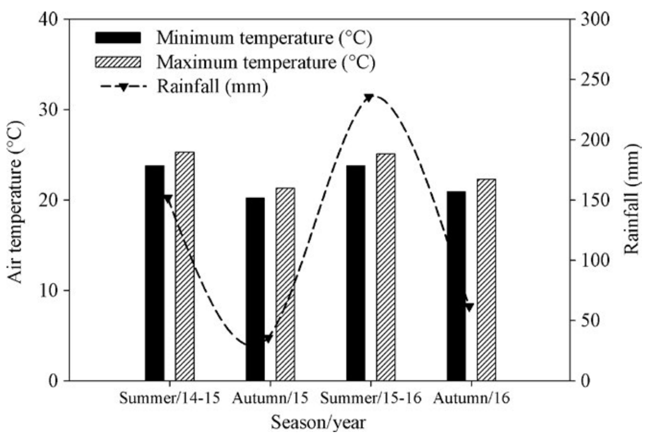

FIGURE 1 Mean minimum and maximum air temperatures (ºC) and rainfall (mm) during experimental period

Between 1998 and 2000, the pastures remained closed to guarantee the initial growth of the tree species. In 2001 and 2002, the pastures were used for the grazing of dry cows, respecting periods of occupation of 5 days and resting of 45 days. During the period between 2003 and 2013, the area was managed with growing heifers. In 2003–2010 grazing management was carried out under rotational stocking and without fertilization and from 2011 to 2013 under continuous stocking and with application of 64 kg/ha of N and K_2O and 16 kg/ha of P_2O_5 per year. For the present study, there were no additional applications of fertilizers or correctives, being characterized as a system with low input and extensive use (low stocking rate and lenient grazing), to guarantee the permanence and sustainability of the pastures after the 17th and 18th years of establishment.

Percentage of shading was measured using the AccuPAR LP-80 (Decagon Devices, Pullman, WA, USA), in which non-destructive measurements were performed on PAR arriving in the understory. Ten measures were carried out in seven different sites of paddock in the SPS, according to the influence of the shading on the pasture. In the OP, PAR measurements were performed at random on the paddock. Measurements were made on clear days (no clouds) at 09:00, 12:00 and 15:00 hr at 1 m above ground level. Mean flux densities of photosynthetic photons were 1,010 and 532 μmol m^{-2} s^{-1} in the SPS and 1,953 and 1,151 μmol m^{-2} s^{-1} in the OP for summer and autumn respectively. From these data, a reduction of 51% in the PAR on the SPS was calculated, in relation to the OP.

In order to characterize the tree component, tree measurements were performed in October 2016. The trees of *E. grandis* had an average height of 29 m and a diameter breast height (DBH) of 45 cm, with 50 trees per ha. The trees of *A. mangium* presented 14 m of height and 32 cm of DBH, with 16 trees per ha. In addition to eucalyptus and acacia, there were 15 trees per ha of *M. artemisiana*, which were not measured but contributed to the total density of 81 trees per ha 18 years after planting.

2.2 | Experimental design and treatments

The experimental design included randomized complete blocks, attributable to varied terrain and patchy soil fertility, with two treatments and three replications, in arrangement of subdivided plots with repeated measures in time. The treatments consisting of the type of system evaluated (SPS and OP) were allocated in the plots. Each plot consisted of a paddock with an area of 1.4 ha, totalling six paddocks (three in the SPS and three in the OP), with a total experimental area of 8.4 ha. In the subplots, the seasons of the year (summer and autumn) were allocated. Another 6 ha (3 ha for the SPS and 3 ha for the OP) was used for the management of extra animals, which are also used for put-and-take grazing management.

2.3 | Animals and pasture management

All procedures involving animals during the study were approved by the Embrapa Livestock Ethics Committee (protocol No. 02/2013). The grazing began in the middle of October of each experimental year to allow adaptation of the animals and the pasture to then begin the evaluations. The experimental period within each year comprised, on average, 180 days.

Grazing management was carried out using the continuous stocking method with a variable stocking rate, aiming to maintain grass height at the pre-determined target of 35 cm (Fernandes, 2016), characterized as *put-and-take* (Allen et al., 2011). Each paddock was grazed by three crossbred (Holstein x Gyr) dairy heifers, aged approximately 12 months and with an average initial body weight (BW) of 200 kg in 2014/2015 and 240 kg in 2015/2016, for a total of 18 animals in each experimental year. The crossbred (Holstein × Gyr) animals were widely used in pasture-based milk production systems in Brazil, due to the high production of Holstein milk and Gyr resistance to tropical climatic conditions. Other extra heifers (grazers) were placed and removed from each paddock according to the need to maintain the canopies at the pre-determined target height of 35 cm (assuming 10% variation). The animals were selected based on weight and similar genetic composition. During the experimental period, the animals received water and mineral supplementation ad libitum. Vaccinations against foot-and-mouth disease, rabies and leptospirosis were carried out annually. The control of *Rhipicephalus (Boophilus) microplus* was performed every 28 days.

2.4 | Measurements

Canopy height was monitored weekly using a ruler graduated in centimetres. Measurements were made at 140 points per paddock. In the SPS, 70% of the measurements were performed between tree rows and 30% within tree rows. This stratification was made considering the influence of shading on the structural characteristics of the pasture.

Forage mass was estimated by direct (destructive) sampling every 28 days. For this, 12 samples were collected in each paddock using a metal frame of 0.25 m^2 (0.50 × 0.50 m) and a cleaver in places where the height of the pasture was 35 cm (target height). In the SPS, four samples were collected in the area within the rows of trees and eight samples in the inter-rows in order to represent the areas with higher and lower incidence of PAR. The plants were cut at a height of 5 cm above the soil level and then taken to the laboratory for weighing and separation of two subsamples. One 300-g subsample was placed in a forced air ventilation and dry matter content oven at 55°C for 72 hr to determine the dry-matter (DM) content of the total sample. The other 200-g subsample was separated into the green and dead fractions. In the green fraction, the number of vegetative and reproductive tillers (with inflorescence) was counted. Then, the green fraction was separated into leaf blade and stem (stems + sheaths + inflorescence) to determine the morphological composition by manual separation. The materials were dried in a forced air ventilation and dry matter content oven at 55°C for 72 hr, where the DM of their constituents was determined. The green dry mass consisted of the sum of the leaf blade dry mass and stem dry mass, and the total dry mass represented the sum of the green dry mass and the dry mass of the dead material. The total and green forage bulk density was calculated by dividing the mass of the total and green dry forage by the mean height of the forage canopy.

Samples to estimate the nutritive value of the forage were collected every 28 days by the method of hand-plucking grazing proposed by Sollenberger and Cherney (1995), in which the forage is collected manually after observing the grazing habit of the animals. A composite sample was collected in each paddock, totalling six samples (three from the SPS and three from the OP). Immediately after collection, the samples were sent to the laboratory, where they were homogenized, and a 500-g subsample of each paddock was packed in properly identified Kraft paper bags and dried in a forced air ventilation and dry matter content oven at 55°C for 72 hr. After drying, the material was ground in a *Willey*-type knife mill equipped with a 1-mm mesh screen and packed in labelled plastic containers for laboratory analysis. The determination of the chemical composition and in vitro DM digestibility (IVDMD) of the forage was performed at the Animal Nutrition Laboratory of Embrapa Dairy Cattle and analysed for DM, where the samples were returned to the oven at 105°C for 12 hr. Total N content (DM basis) was analysed according to the Kjeldahl procedure (AOAC, 1990). Crude protein (CP) content was calculated as the total N × 6.25. The content of neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) based on DM were analysed according to the methodology proposed by Van Soest, Robertson, and Lewis (1991). IVDMD content was determined according to the technique described by Tilley and Terry (1963).

Stocking rate was calculated based on the weights of the testers animals plus the weights of the regulating animals during the period in which they remained in the paddocks, as well as the total area (ha) of each treatment during each season. It was expressed in animal unit (450/kg BW) per area (ha). Average daily gain (ADG) of the animals was used to estimate the performance of heifers. For this, the animals were weighed at the beginning of the experiment and every 28 days after fasting from solids and liquids for 12 hr. The ADG was obtained by the difference between the weighing divided by 28 (weighing interval). Weight gain per area was calculated by multiplying the ADG of the heifers (testers and grazers) by the stocking rate per paddock and by the number of days they remained in grazing.

2.5 | Statistical analysis

The data were analysed in a randomized complete block design in a subdivided plot scheme with repeated measures in time. The systems were allocated in the whole plot and the seasons of the year in the smallest parcel. Mixed models were used with the PROC MIXED of SAS® (SAS, 2001), considering the system, the season, the year and their interactions as fixed effects and the nested repetition to the production system and the error as random effects. The choice of the covariance matrix was based on the Akaike information criterion (Wolfinger, 1993), adopting the following sources of variation: production system, season, year and their interactions. The averages were compared by Fischer's minimum significant difference, using the PDIFF option of the LSMEANS command. For all analyses, $p \le 0.05$ was defined as the critical level of probability for type I error.

3 | RESULTS

3.1 | Canopy height

During the experimental period, mean canopy heights in the SPS and OP in the summer were 34.6 and 34.9 cm respectively. Mean canopy heights in autumn were 32.5 and 32.9 cm respectively. The canopy height was close to the grass height target of 35 cm. It was verified that the grazing was effective in maintaining the heights within the pre-determined range, indicating that the management recommended with the use of a variable stocking rate was efficient for control of the forage canopy height.

3.2 | Tiller population density, forage mass, forage bulk density and morphological composition

The OP system had higher tillering density ($p = 0.004$), higher total dry mass ($p = 0.005$), higher green dry mass ($p = 0.033$), higher total forage bulk density ($p < 0.001$) and green forage bulk density ($p = 0.029$) than the SPS system (Table 1). In addition, the interactions for SPS and OP traits between seasons were significant. For these variables, the OP presented higher values than the SPS in the summer, but in the autumn, there was no difference between the systems, except for total forage bulk density, which was lower in the SPS. Both systems presented lower values for these variables in autumn when compared to summer.

The percentage of vegetative and reproductive tillers of *B. decumbens* pastures was influenced ($p = 0.007$) by the season. A higher percentage of vegetative tillers was observed in autumn (94.58%) than in summer (88.80%) while a higher percentage of reproductive tillers was verified in summer (11.19%) than in autumn (5.41%).

The stem dry mass was influenced ($p = 0.004$) by the interaction between the type of system and the season of the year (Table 2). The value was higher in the OP when compared to the SPS in the summer. There was no difference between systems in the autumn. Both systems had higher stem dry mass in the summer when compared to the autumn. The leaf blade dry mass was influenced by the interaction between the season of the year and the experimental year ($p = 0.006$; Table 2). The value was higher in the first year when compared to the second year in the summer. However, there was no difference between years in the autumn. In the first year, the leaf blade dry mass was higher in summer compared to autumn. There was no difference between seasons in the second year. The leaf blade dry mass also varied with the type of system ($p = 0.010$), with a greater value in the OP (947 kg/ha) than in the SPS (716 kg/ha).

The dead material dry mass was influenced by the interaction between the type of system and the experimental year ($p = 0.009$)

TABLE 1 Tiller population density, total dry mass, green dry mass, total forage bulk density and green forage bulk density of *Brachiaria decumbens* in silvopastoral system (SPS) and open pasture (OP), during the experimental period

Season	System SPS	OP	*p*-value*	S.E.M.
Tiller population density (tiller/m)				
Summer	657 Ab	819 Aa	0.004	30.50
Autumn	594 Ba	638 Ba		
Total dry mass (kg/ha)				
Summer	2,478 Ab	3,894 Aa	0.005	116.06
Autumn	1,868 Ba	2,390 Ba		
Green dry mass (kg/ha)				
Summer	1,999 Ab	2,845 Aa	0.033	116.31
Autumn	1,431 Ba	1,714 Ba		
Total forage bulk density (kg/cm ha)				
Summer	71.6 Ab	111.5 Aa	<0.001	3.14
Autumn	57.6 Bb	72.7 Ba		
Green forage bulk density (kg/cm ha)				
Summer	57.9 Ab	81.3 Aa	0.029	3.30
Autumn	44.1 Ba	52.2 Ba		

Notes. S.E.M.: standard error of the mean.
Means followed by different letters, lowercase letters in the same row and uppercase letters in the same column, are different by PDIFF ($p < 0.05$).
*Probability of significant effect due to interaction between the season and system ($p < 0.01$; $p < 0.05$).

and between the season of the year and the experimental year ($p < 0.001$; Table 3). The OP showed higher dead material dry mass when compared to the SPS in both experimental years. A lower value was observed in the first year in both systems when compared to the second year. In the first year, there was no difference between seasons, but a lower value was observed in the autumn than in the summer in the second year. A greater value was observed in the second year in relation to the first, regardless of the season.

3.3 | Nutritive value

Crude protein content in the forage is presented in Figure 2, with comparisons being made between silvopastoral system and OP and experimental years. CP content was influenced ($p = 0.037$) by the interaction between the type of system and experimental year. Higher CP was observed in the SPS (109 and 128 g/kg) than in the OP (87 and 96 g/kg), regardless of the experimental year. There was a 25% and 33% increase in CP concentration in SPS relative to OP during the first and second experimental years respectively. Both systems had lower CP in the first experimental year.

The content of NDF in forage was influenced only by the type of system ($p = 0.001$), with lower value for the SPS (658.1 g/kg) than for the OP (676.6 g/kg). The ADF and ADL contents were influenced ($p = 0.027$, $p = 0.007$ respectively) by the interaction between the type of system and the season of the year (Figure 3a,b). The ADF content did not vary between systems in the summer. However, there was a reduction in ADF in the SPS when compared to the OP in autumn. The content of ADL did not vary by system, regardless of the season of the year. Lower levels were observed during autumn when compared to summer in both systems. IVDMD content did not differ ($p = 0.595$) with the system, season or experimental year, nor with the interaction among these factors (mean value of 653.6 g/kg).

3.4 | Stocking rate and animal performance

The stocking rate and weight gain per area were influenced only by the type of system ($p = 0.023$, $p = 0.012$ respectively; Table 4). In the OP, stocking rate and weight gain per area were, respectively, 7% and 13% higher than in the SPS during the experimental periods.

The ADG varied with the interaction between the type of system and the experimental year and with the season of the year and the experimental year ($p = 0.012$, $p = 0.002$ respectively; Table 5). The ADG did not differ between systems in the first year. In the second year, the animals in the OP had higher ADG than in the SPS. There was higher ADG in the second year when compared to the first year in the OP, whereas there was no difference between the years for the SPS. In the first experimental year, higher ADG was observed in the autumn compared to the summer. In the second year, there was

TABLE 2 Stem dry mass and leaf blade dry mass of *Brachiaria decumbens* in silvopastoral system (SPS) and open pasture (OP) during the experimental period

Season	System SPS	OP	*p*-value*	Year 2014/2015	2015/2016	*p*-value*
	Stem dry mass (kg/ha)			Leaf blade dry mass (kg/ha)		
Summer	1,194 Ab	1,783 Aa	0.004	1,122 Aa	742 Ab	0.006
	(82.59)	(85.59)		(65.43)	(30.11)	
Autumn	802 Ba	880 Ba		784 Ba	678 Aa	
	(82.59)	(85.59)		(65.43)	(30.11)	

Notes. Means followed by different letters, lowercase letters in the same row and uppercase letters in the same column, are different by PDIFF ($p < 0.05$).
Values in parentheses represent the standard error of the mean.
*Probability of significant effect due to interaction between the season and system ($p < 0.01$) and season and year ($p < 0.01$).

TABLE 3 Dead material dry mass (kg/ha) of *Brachiaria decumbens* in silvopastoral system (SPS) and open pasture (OP), during the experimental period

	System			Season		
Year	SPS	OP	*p*-value*	Summer	Autumn	*p*-value*
2014/2015	382 Bb (54.35)	597 Ba (54.35)	0.009	517 Ba (54.35)	462 Ba (54.35)	<0.001
2015/2016	607 Ab (54.35)	1,128 Aa (54.35)		1,115 Aa (54.35)	621 Ab (54.35)	

Notes. Means followed by different letters, lowercase letters in the same row and uppercase letters in the same column, are different by PDIFF ($p < 0.05$).
Values in parentheses represent the standard error of the mean.
*Probability of significant effect due to interaction between the year and system ($p < 0.01$) and year and season ($p < 0.01$).

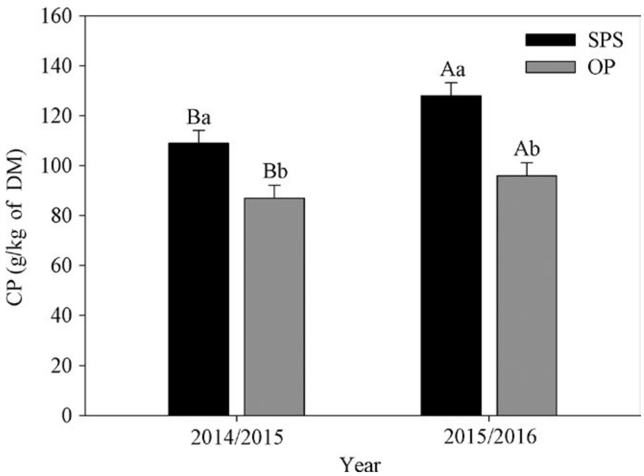

FIGURE 2 Crude protein (CP) content of *Brachiaria decumbens* in silvopastoral system (SPS) and open pasture (OP) during the years of experimental period. Means followed by different letters, lowercase letters comparing the systems in each year and uppercase letters comparing each system in the years, are different by PDIFF ($p < 0.05$)

no difference in ADG between seasons. In the summer, the ADG was lower in the first year compared to the second year. In the autumn, there was no difference between the evaluation years in the ADG.

4 | DISCUSSION

According to our hypothesis, an increased ADG would be expected in the SPS due to the higher CP content in the forage. However, contrary to our expectations, an opposite response was observed in the second year of the study. We also hypothesized that the more intense shading in SPS would negatively affect pasture productivity, leading to a lower stocking rate and weight gain per unit area. This hypothesis was based on the observation that tree growth over time progressively reduced the incidence of radiation available for pasture growth. Indeed, the OP allowed for a higher stocking rate and resulted in an increased body weight gain per unit area in comparison with SPS, confirming our second hypothesis.

Although the SPS provides better thermal comfort (Murgueitio et al., 2011) and higher CP, severe shading reduced forage dry mass and forage bulk density, which may have a negative influence on the ingestive behaviour of the animals. In previous years, Paciullo et al. (2009) observed, in the same systems, higher daily gain for dairy heifers grazing in the SPS than in the OP or similar gain between systems (Paciullo et al., 2011). The authors attributed the greater gain per heifer to the higher CP in the SPS. At that time, the SPS and OP presented the same forage mass. Despite the higher CP in the SPS in the present study, no benefit was observed for ADG, indicating that severe shade neutralized potential benefits in the SPS and may limit the weight gain of heifers. Although statistically significant, the 20% decrease in daily gain in the SPS compared to the OP in the second year is not considered a difference of great magnitude.

The OP provided a higher stocking rate and weight gain per area than the SPS. This can be explained by the higher forage mass and forage bulk density in the OP, increasing the pasture carrying capacity. Although severe shading had a negative influence on the pasture productive characteristics in the SPS, the reductions in stocking rate and weight gain per area in the SPS in relation to the OP were not of great magnitude (6.0% vs. 13.2% respectively), also observed for individual weight gain. The extensive management was used according to the need to adapt to the existing limitations, such as sloping area and soil with low natural fertility. This may have contributed to the small magnitude differences in carrying capacity and weight gain per area in favour of the OP. In the study of Fernandes (2016), developed in the same experimental area of this work, it was suggested that the degree of reduction in forage and animal production in the SPS is directly related to the level of intensification of the system. Pastures grown in the SPS that are not intensified in terms of inputs, especially fertilizers, seem to present greater resilience when subjected to the limitation of incident radiation. For this reason, they may present a less intensive drop in productivity and take a longer period of time to reflect the negative effects of decreased radiation on grass. In spite of the extensive pasture management, the ADG varying between 0.400 and 0.583 kg^{-1} day^{-1} can be considered satisfactory, since the animals were exclusively pasture-fed. Crossbred dairy heifers should gain 0.400 kg^{-1} day^{-1} if the target is conception

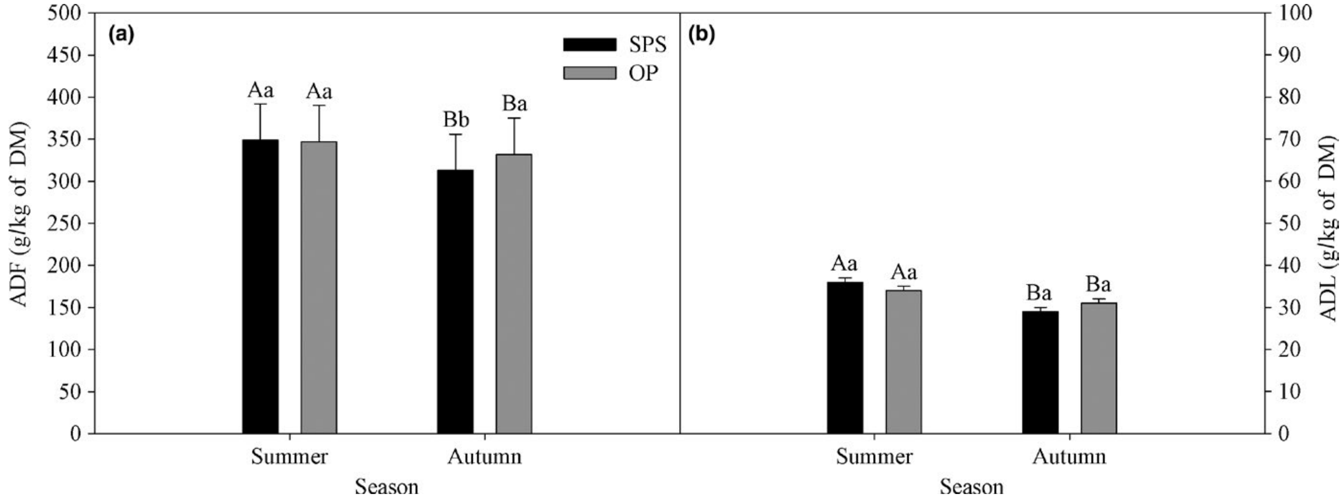

FIGURE 3 Acid detergent fibre (ADF; a) and acid detergent lignin (ADL; b) content of *Brachiaria decumbens* in silvopastoral system (SPS) and open pasture (OP) in the summer and autumn of the experimental period. Means followed by different letters, lowercase letters comparing the systems in each season and uppercase letters comparing each system in the seasons, are different by PDIFF ($p < 0.05$)

at 24 months of age (Gomide, Paciullo, & Alexandrino, 2010). The values obtained for both systems were always above this value.

An important variable of pasture structure that influences the forage mass and animal performance is tiller population density. The lower value in the SPS is directly related to the shading imposed by trees on the pasture (Abraham et al., 2014). Grass under shade prioritizes the growth of existing tillers, to the detriment of the formation of new tillers, inhibiting development of the basal buds that will give rise to new tillers and, therefore, reducing the tiller population density. Average percentage of shading in the SPS of 51% can be considered severe for *B. decumbens*, according to other authors, who verified reductions in tillering with shading (Devkota, Kemp, Hodgson, Valentine, & Jaya, 2009; Gobbi et al., 2009).

The decrease in tiller population density observed under shading, affected the total and green dry masses, which were higher in the OP than in the SPS, during the summer. These results followed a similar pattern of response to tiller population and emphasized the negative effect of severe shading on pasture in the SPS, especially in the summer. Decreases in the forage productions in shaded systems were observed by other authors (Bosi, Pezzopane, Sentelhas, Santos, & Nicodemo, 2014; Neel & Belesky, 2017; Santos et al., 2016). The strong restriction of PAR compromises the photosynthetic capacity of the plants, reducing the production of the components of the forage mass (Santiago-Hernández et al., 2016).

The decrease in total forage bulk density in summer and autumn in the SPS in relation to the OP was due to the fact that total dry mass was lower in the SPS, considering that the canopy height at the time of harvest was the same for both systems. The adequacy in the adjustment of the stocking rate was a strategy that helped maintain the pre-established target of height in continuous stocking. The low forage bulk density observed in the SPS could decrease the bite size and the ingestion of forage by the animals, resulting in compromised animal production in the SPS. Lopes et al. (2017) observed a decrease in forage bulk density with an increase in the level of shading, corroborating the results of the present study.

It is interesting to note that, despite the higher stem dry mass in the OP, the stem proportions in the total dry mass were practically equal between the systems. Thus, it was possible to calculate proportions of 47% and 46% of stems in the dry mass for the SPS and OP respectively. Results obtained from the calculation of the proportion of leaves in the total dry mass revealed that the proportion of leaf blades in the dry mass was 21% higher in the SPS than in the OP (29% vs. 24% leaf blades, respectively, for SPS and OP). In fact, shading induces morphological changes in the pasture in order to increase light uptake (Paciullo et al., 2017). This result can be associated with small magnitude of differences between systems in heifers weight gain, during experimental period, because the higher leaf blade proportion may have contributed positively to animal nutrition in SPS, despite lower forage mass, tiller population density and forage bulk density in this system than in OP. The greater investment of the plant in the leaf blades component under shading may contribute to the higher proportion of leaves in the SPS. Besides that, it should also be considered that plants that develop in shady environments may present longer leaf longevity, keeping them green for a longer period (Lopes et al., 2017). Thus, as the leaves remain green longer, there is less tissue renewal in the plant, contributing to lower dead material dry mass in the SPS.

The OP presented higher dead material dry mass when compared to the SPS, regardless of the experimental year. Pastures growing in open conditions present higher photosynthetic rates than shaded pastures, providing accelerated development and tissue death. The *B. decumbens* is a tropical grass of C_4 metabolism that is highly responsive to edaphoclimatic conditions. On the other hand, shade-grown plants tend to present morphological maturity delay of 4–6 days in relation to plants grown in OP (Neel, Felton, Singh, Sexstone, & Belesky, 2016). In this case, plants tend to be younger

TABLE 4 Stocking rate and weight gain per area of dairy heifers (Holstein x Gyr) grazing *Brachiaria decumbens* in the silvopastoral system (SPS) and open pasture (OP), during the experimental period

	System			
Variable	SPS	OP	*p*-value*	S.E.M.
Stocking rate (UA/ha)	1.4 b	1.5 a	0.023	0.02
Weight gain per area (kg/ha BW)	96.0 b	110.6 a	0.012	2.76

Notes. S.E.M.: standard error of the mean.
Means followed by different lowercase letters in the row are different by PDIFF ($p < 0.05$).
*Probability of significant effect due to system ($p < 0.05$).

physiologically, which prolongs the vegetative phase, reducing senescence and dead material dry mass (Lopes et al., 2017).

Highest CP content in the SPS compared to the OP in the present study is consistent with results found in other studies (Abraham et al., 2014; Neel & Belesky, 2017; Paciullo et al., 2017) and could represent a nutritional advantage to SPS, although no apparent benefit was observed for animal performance. Lazzarini et al. (2009) suggested have CP values 70 g/kg of DM for crossbred heifers, at least to avoid compromising the ruminal microbial growth and, consequently, for the efficient use of the fibrous carbohydrates of the forage. CP content during the experimental period in both systems was always greater than 70 g/kg of DM, optimizing microbial activity, forage intake, digestibility and animal performance.

Increase in the CP content in shaded environments may be related to both the direct effect of shading on the physiological characteristics of the forage and the effect of nitrogen (N_2) dynamics on the soil. Belesky, Chatterton, and Neel (2006) report a delay mechanism in ontogenetic development in shaded plants. With this, plants tend to be younger physiologically, maintaining higher metabolic levels. Wilson and Ludlow (1991) argue that light reduction causes a decrease in photosynthesis, resulting in an increase in the concentration of N. Dale and Causton (1992) relate a higher content of N in shaded plants with the theory of dilution as a function of the increase in CP in the plant; in other words, with shading, there is a reduction in forage production, and the amount of N absorbed may exceed the metabolic requirement, increasing N content without increasing forage production. Another mechanism may be related to the greater conservation of soil moisture and, consequently, greater mineralization and decomposition of organic matter, increasing the availability of N to the forage (Wilson, 1996). The presence of the tree legumes *A. mangium* and *M. artemisiana*, which have the capacity to fix the atmospheric N and to incorporate it into the soil, may have contributed to the increased mineralization of organic matter in the SPS, increasing the flow and availability of N in the soil and, consequently, the CP content in forage in the SPS (Xavier et al., 2014).

While CP content usually increases with shading, NDF, ADF, IVDMD and ADL do not present a defined pattern, and the results depend on species, time of year and percentage of shading. In this study, the lower NDF content in the SPS was probably related to the decrease of photoassimilates, resulting in thinner cell walls than in the OP (Kephart & Buxton, 1993). The IVDMD did not vary with the system and can be explained by the similarity in the levels of ADF and ADL found between the systems. However, there was a reduction in both ADF and ADL content in both systems in the autumn, which is associated with the decrease in PAR, temperature and precipitation, reducing forage growth.

Effects of the seasons of the year on the studied variables were related to the climatic variations inherent to each season. The similarity of ADG in the first year can be explained by the lower availability of rainfall, limiting forage production and possibly forage intake by the animals in both systems. Adverse climatic conditions tended to equalize the systems, even considering the severe shading in the SPS. In the second year, the highest ADG was observed in the OP. Apparently, no evaluated characteristic could explain this result, mainly because there was adjustment of the stocking rate, according to the target of canopy height. However, the higher rainfall in the second year (Figure 1) may have favoured OP characteristics not evaluated, such as forage intake.

The lower ADG observed in the summer of the first year when compared to autumn can be explained by the low rainfall during January and February, resulting in a reduction in forage production and, consequently, limiting forage intake by the animals. In the second year, when there was a better distribution of rainfall, there was no difference in ADG between the seasons. Additionally, the

TABLE 5 Average daily gain (ADG; kg/day$_{-1}$) of dairy heifers (Holstein x Gyr) grazing *Brachiaria decumbens* in the silvopastoral system (SPS) and open pasture (OP) during the experimental period

	System			Season		
Year	SPS	OP	*p*-value*	Summer	Autumn	*p*-value*
2014/2015	0.483 Aa (0.01)	0.483 Ba (0.01)	0.012	0.400 Bb (0.01)	0.566 Aa (0.01)	0.002
2015/2016	0.466 Ab (0.02)	0.583 Aa (0.02)		0.516 Aa (0.02)	0.533 Aa (0.02)	

Notes. Means followed by different letters, lowercase letters in the same row and uppercase letters in the same column, are different by PDIFF ($p < 0.05$).
Values in parentheses represent the standard error of the mean.
*Probability of significant effect due to interaction between the year and system ($p < 0.05$) and year and season ($p < 0.01$).

intense flowering of *B. decumbens* may have had a negative influence on the grazing behaviour of the animals. Indeed, a higher proportion of reproductive tillers was observed during the summer, as observed by (Santos, Fonseca, Gomes, Castro, & Carvalho, 2011; Santos, Gomes et al., 2011). Although the *B. decumbens* flowers throughout the year, characterizing it as a neutral day plant, this phenomenon is usually more pronounced on long summer days (Fonseca & Martuscello, 2010b). It is also possible to associate the highest percentage of reproductive tillers in the summer to the gradual flowering of pasture between December and mid-January of each experimental year. While the apical meristem of many tillers remained intact during grazing, there was intense flowering of tillers not yet grazed. In these tillers, there was a higher priority in the allocation of photoassimilates for inflorescence emission than for vegetative growth. Since then, with the stabilization of height and elimination of most of the apical meristems, a reduction in the number of reproductive tillers was observed, especially in late summer and throughout autumn. The reduction in the percentage of reproductive tillers in the fall can also be explained by the less favourable climatic conditions in this season.

Significant difference in tiller population density between systems, in the summer, was related to the best conditions of temperature, rainfall and brightness in the summer favouring tillering in the OP, but with had less of an impact in SPS, due to the limitation of PAR to the pasture. In autumn, no significant difference was detected. This fact can be attributed to the less favourable climatic conditions associated with this season, which had a negative influence on the tillering of both systems and resulted in the absence of a difference in tiller population density between systems.

Although the forage mass values were higher in the OP during the summer, no differences were observed between the systems in the autumn, which is associated with the seasonality of the production of tropical forages due to the limitation of climatic conditions. Gobbi et al. (2009) did not observe a difference in *B. decumbens* forage mass at 50% and 70% artificial shade levels and in full sun during the period of reduced availability of growth resources.

5 | CONCLUSION

In a long-term silvopastoral system, strong light competition between the tree component and the pasture results in a decrease in forage productivity when compared to open pasture. Severe shading should be avoided through silvicultural interventions such as thinning and pruning of trees in silvopastoral system that focus on animal production in order to stabilize forage yield, which will help maintain the long-term the overall system performance of the system. The higher crude protein content and lower fibre in the silvopastoral system may constitute a nutritional advantage for the animals, resulting in satisfactory performance even with severe light restriction. The extensive response of *B. decumbens* with a severe level of shading, as observed in the present study, suggests a high degree of phenotypic plasticity in terms of productivity, even after a long period of use under animal grazing.

ACKNOWLEDGMENTS

The authors wish to thank the Fundação do Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Instituto Nacional de Ciência e Tecnologia–Ciência Animal (INCT–CA) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for their financial support.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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How to cite this article: Lima MA, Paciullo DSC, Morenz MJF, Gomide CAM, Rodrigues RAR, Chizzotti FHM. Productivity and nutritive value of *Brachiaria decumbens* and performance of dairy heifers in a long-term silvopastoral system. *Grass Forage Sci*. 2019;74:160–170. https://doi.org/10.1111/gfs.12395