

Enteric methane in grazing beef cattle under full sun, and in a silvopastoral system in the Amazon

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Abstract – The objective of this work was to evaluate the quality of pasture and enteric methane (CH₄) emission of Curraleiro Pé-duro x Nelore cattle in a pasture of *Megathyrus maximus* 'Mombaça', both in full sun and in a consortium with babassu palms (*Attalea* spp.) in the Amazonian biome. The experimental design was completely randomized, with six steers per system, and the evaluations were done during the dry period (2015) and rainy period (2016). In comparison to forage in the full sun system, forage in the silvopastoral system showed, in the dry period, higher levels of crude protein, ether extract, total digestible nutrient, and in vitro digestible organic matter, and lower levels of dry matter, neutral detergent fiber, and total carbohydrate (TCHO). In the rainy period, forage in the silvopastoral system showed higher levels of crude protein and a reduction of nonfibrous carbohydrate and TCHO. The CH₄ emissions were similar in both systems within the same period, and ranged from 44.0 to 74.2 kg per year per animal. During the dry period, the emission per kilogram of dry ingested matter and the loss of gross energy as methane were lower in the silvopastoral system. During the rainy period, the emissions were similar in both systems. The silvopastoral system yields forage with good quality in the dry period, and considering both periods, it is more efficient (emission of CH₄ per daily weight gain) than the system in full sun.

Index terms: CH₄, Curraleiro Pé-duro, greenhouse gases, livestock farming, Nelore.

Metano entérico de bovinos em pastagem a pleno sol e em sistema silvopastoril na Amazônia

Resumo – O objetivo deste trabalho foi avaliar a qualidade da pastagem e a emissão de metano (CH₄) entérico de bovinos Curraleiro Pé-duro x Nelore, em pastagem de *Megathyrus maximus* 'Mombaça', tanto a pleno sol como em consórcio com palmeiras de babaçu (*Attalea* spp.), no bioma Amazônia. O delineamento experimental foi inteiramente casualizado, com seis novilhos por sistema, e as avaliações foram realizadas nos períodos seco (2015) e no chuvoso (2016). Em comparação à forragem no sistema a pleno sol, a forragem no sistema silvopastoril apresentou maiores teores de proteína bruta, extrato etéreo, nutrientes digestíveis totais e digestibilidade in vitro da matéria orgânica, e menores teores de matéria seca, fibra em detergente neutro e carboidratos totais (CHOT). No período das águas, o sistema silvopastoril apresentou maiores teores de proteína bruta e reduções de carboidratos não fibrosos e CHOT. As emissões de CH₄ foram semelhantes entre os sistemas, tendo variado de 44,0 a 74,2 kg por animal por ano. No período seco, a emissão por quilograma de matéria seca ingerida e a perda de energia bruta por metano foram menores no sistema silvopastoril. No período chuvoso, as emissões foram similares entre os tratamentos. O sistema silvopastoril oferece pastagem de boa qualidade na seca e, considerando-se o ciclo com ambos os períodos, é mais eficiente (emissão de CH₄ pelo ganho de peso diário) do que o sistema a pleno sol.

Termos para indexação: CH₄, Curraleiro Pé-duro, gases de efeito estufa, pecuária, Nelore.

Introduction

The Amazon biome occupies 49.3% of the Brazilian territory, and it is characterized by a rich

biodiversity, high temperatures, and high humidity (IBGE, 2017). Livestock farming stands out as a great income generator because the region has more

than 80 million head of cattle, accounting for 38% of the national herd (Produção..., 2014), making it the second largest commercial herd in the world (FAO, 2013). The most widely used production system is grazing, based on the consumption of tropical forage grasses, generally with low-nutritional value (Dias-Filho, 2014). As a result, Brazilian livestock farming is internationally recognized as an activity that has a great impact on enteric methane emission (Metz et al., 2007). Methane emissions in the agricultural sector of the country are estimated at 63.2% coming from the enteric fermentation and, from this percentage, 97% come from cattle farming for beef production (Brasil, 2010).

Despite the great importance of this activity, Brazil lacks studies that quantify these emissions, and that indicate mitigating measures for the most varied production systems and different biomes. Possible mitigating measures in this sector include: the rational use of pastures, supplementation, adoption of integrated systems, and the use of animals that are adapted to the environment (Thornton & Herrero, 2010). These measures aim to improve animal productivity, and reduce methane emission per kilogram of generated product.

The presence of native breeds in the Brazilian territory opens up a range of opportunities for use in hot climate regions. Adapted crossings between *Bos indicus* and *Bos taurus* subspecies, such as Curraleiro Pé-duro (CPD) breed, have been gaining prominence mainly for the quality of its meat and resistance to dry periods (Carvalho et al., 2013). In the current scenario of climate change, the presence of these animals represents a genetic asset of great value, mainly because they are highly resistant and adapted to heat (Azevêdo et al., 2008).

In the eastern part of the Amazon biome and in its border with the Cerrado, approximately one million people live off the extractivism of babassu (*Attalea* spp.) (Promoção..., 2009). In these regions, the use of a combination of pasture and palm trees is common. This system is empirically considered as a means for halting deforestation, and improving pasture conditions, thereby making animal farming more sustainable. However, there are no studies on the contribution of these environments to beef production, nor on the emissions generated, nor are there any reports on the

emission of enteric methane by native animals, or on fully adapted crossbreeds to the environment.

The objective of the present work was to quantify the enteric methane emissions by animals of the Curraleiro Pé-duro breed, which are adapted to the tropics, and compare the quality of 'Mombaça' grass pasture, in a silvopastoral system with babassu palms, and a pure pasture under full sun conditions in the Amazon biome.

Materials and Methods

The study was carried out in the municipality of Codó (04°27'19"S and 43°53'08"W, at 47 m altitude), in the state of Maranhão, Brazil. The soil type of the region is classified as Red-Yellow Acrisol (Santos et al., 2013). The climate is classified as Aw (tropical, wet and dry), with 27.4°C mean temperature, and 1,526 mm mean annual rainfall. The distribution of rainfall is irregular, with 80% occurring between January and May, which corresponds to the wet season; the remaining months comprise the dry season, and the period between August and December is considered critical.

The experimental period included the dry season of 2015, in May and August, and the wet season of 2016, in January and April. Data on rainfalls, obtained with a rain gauge during the study period, are shown in Figure 1.

The evaluations took place in a total area of 5.88 ha, equally divided into two pasture areas, which corresponded to two systems. The first system was composed of pure pasture of 'Mombaça' grass [*Megathyrsus maximus* (Jacq.) B.K.Simon & Jacobs (Syn. *Panicum maximum* Jacq.)] under full sun conditions. In the second system, the pasture was combined with babassu trees (*Attalea speciosa* Mart.). This area contained 196 randomly distributed trees (a mean of 67 trees ha⁻¹), with heights ranging from 15 to 20 m, representing a natural system of livestock farming/forest integration. The shaded area was calculated by determining the shade area of the canopy at noon, using a measuring tape. The pastures of both systems were established simultaneously in 2013, and the areas were adjacent.

Each rotational grazing area was composed of seven 4,200 m² paddocks. The grazing period was four days, with a constant starting height of approximately 80 cm, an ending height of 40 cm, and a variable stocking rate

(Silva & Nascimento Júnior, 2007). The experiment included 12 crossbred calves obtained from a Nellore and Curraleiro Pé-Duro crossing (CPD-Nellore) born in March and April 2014. The initial mean weight of the animals was 185 ± 26 kg, they were equally divided into two plots and distributed in the grazing areas. Another 18 beef cattle were used for any adjustment of forage height. The animals fed forage and mineral salt which were provided ad libitum. The animals entered the paddocks after pasture levelling by mechanical clearing on May 1, 2015 (dry period) and January 3, 2016 (rainy period); the starting forage height was obtained after 24 days. Forage height was measured daily using a ruler, at 50 different points of each paddock. The cattle were weighed using electronic scales every 28 days after water and food fasting for 12 hours. The animals were kept in the experimental area for four months, in the dry period (from May to August 2015), and for another four months in the rainy period (between January and April 2016). At the end of each month, the animals were weighed, totalling eight weighings. Forage quality, enteric methane emission, dry matter intake, and animal performance were evaluated simultaneously.

To estimate the production of dry matter per hectare, samples of pasture were collected in the two systems, by using the no-till farming method (Lopes et al., 2000) in 1 m^2 areas. Two samples were

collected per paddock, during two consecutive cycles, totalling 28 samples per system in each period. A subsample was retrieved from the collected biomass and botanically separated into leaf lamina, stem and margin, and senescent material. These fractions were weighed before and after drying in a forced-air oven at 65°C for 72 hours, to determine the dry matter (DM) content. Subsequently, the contents in total forage dry mass (TFDM), green forage dry mass (GFDM), green leaf lamina dry mass (GLLDM), stem dry mass (SDM), and dead forage dry mass (DFDM) were calculated.

The forage samples for the analysis of nutritional value were collected on the days in which the methane sample collection and intake tests were performed, with a total of six samples per paddock, both in the dry and rainy periods. The forage samples were obtained by simulated grazing, to obtain samples similar to the fractions actually consumed by the animals. They were then predried in a forced-air oven at 65°C for 72 hours, and ground in a Wiley-type mill with a 2 mm mesh sieve. The contents of DM, crude protein (CP), mineral matter (MM), ether extract (EE), neutral detergent fiber (NDF), and acid detergent fiber (ADF) were determined according to Silva & Queiroz (2006). The phosphorous content was determined by colorimetry, and the calcium content was determined using a Hitachi AAS Z-5000 polarized Zeeman atomic absorption spectrophotometer (Thermo

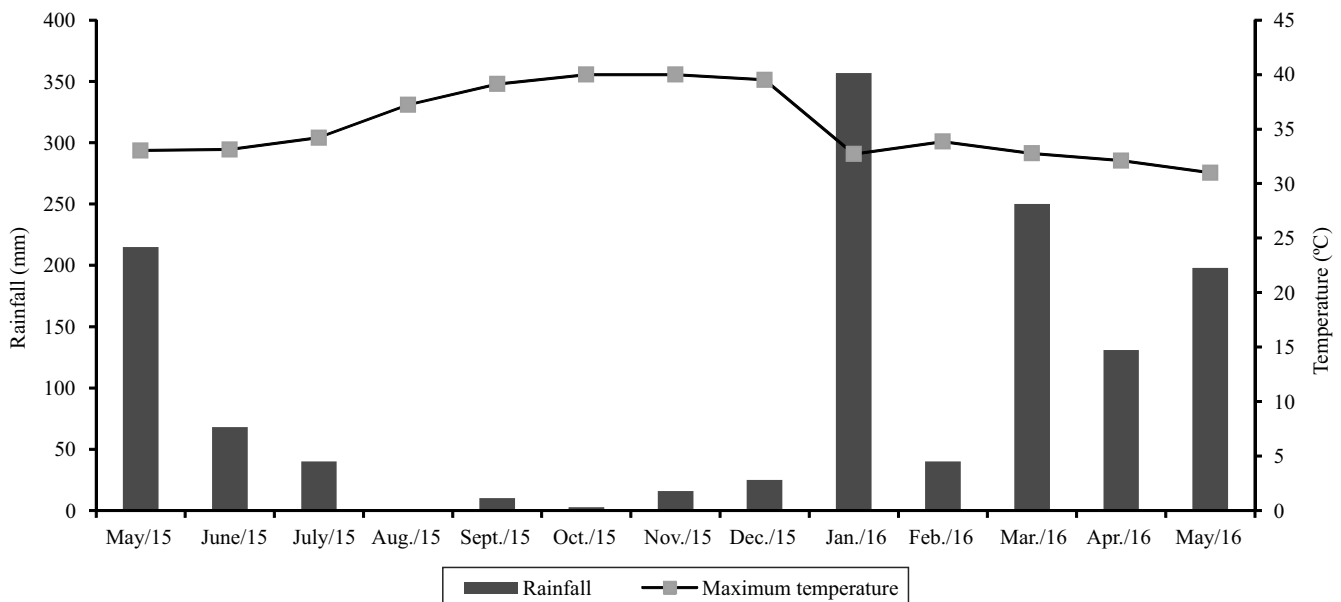


Figure 1. Data on rainfall and maximum temperatures recorded during the experiment.

Scientific, Hemel Hempstead, UK). The nonfiber carbohydrate, total carbohydrate, and total digestible nutrient contents were calculated using the following formulae: $NFC = 100 - (CP + EE + MM + NDF)$, $TCHO = NDF + NFC$, and $TDN = -2.49 + 1.0167DMO$, respectively, according to Cappelle et al. (2001). Gross energy was obtained by sample combustion in an adiabatic calorimeter (PARR Instruments, Illinois, USA).

The intake of forage dry matter (FDM) was estimated by the indirect method, in which intake is considered as the ratio between daily fecal production and the digestibility of consumed forage (Lima et al., 2008). Fecal production was estimated using the purified isolated lignin (LIPE) as external indicator, as described by Lima et al. (2008).

To determine the *in vitro* digestibility of dry matter (IVDDM) of the grazed forage, simulated grazing was used for six consecutive days in the dry and rainy periods. After collection, the samples were dried in a forced-air oven at 65°C, for 72 hours, and processed in a mill with a 1 mm mesh sieve. At the end of the period, they were homogenized into composed samples corresponding to each collection day. The samples were subjected to the *in vitro* digestibility procedure, using the modified two-stage method (Santos et al., 2000) in an automated Ankom Daisy^{II} Incubator (Ankom Technology, New York, USA).

Enteric methane emissions by grazing animals were determined by the sulphur hexafluoride (SF₆) tracer gas technique described by Johnson & Johnson (1995), adapted for Brazil by Primavesi et al. (2004), and improved by Lambert (2014). In this technique, a permeation tube that emits sulphur hexafluoride (SF₆) gas at a known constant flow rate is inserted in the rumen. It is assumed that the pattern of SF₆ emission simulates that of CH₄ emission, and methane in the sample is quantified based on SF₆ concentration. Gas expelled by the animals' mouth and nostrils is aspirated through a device secured to a fitted halter, and connected to a vacuum PVC canister (yoke) that is placed on the animal's neck (Johnson & Johnson, 1995). After each collection period, the yokes were sent for chromatography analysis, to determine SF₆ and CH₄ concentrations. The CH₄ collections were performed for five consecutive days, and the yokes were changed every 24 hours. The yokes were left on during the entire period, in order to collect the blank sample under similar environmental conditions to

those to which the animals were subjected, but distant from them to avoid contamination.

The animals were fitted with the sampling apparatus (yokes and halters) for 20 days. The collections were performed in the dry (08/24/2015 to 08/29/2015) and rainy (04/04/2016 to 04/09/2016) periods. The first day of collection coincided with the animals' entry to the paddock, in both systems, to achieve a uniform age of the plant during the assessment.

Concentrations of CH₄ and SF₆ collected in the yokes were determined by gas chromatography with a flame ionization detector and an electron capture detector (HP6890-Agilent, Delaware, USA), respectively (Primavesi et al., 2004). The analyses were performed immediately after the field collection periods, in the laboratory of Embrapa Meio Ambiente, enabling reuse of the yokes in the subsequent collection period. Gas chromatography results enabled the methane emission factor to be determined in grams of CH₄ per day (CH₄gd), or in kilograms of CH₄ per year (CH₄ky).

The study had a completely randomized experimental design. The exploratory data analysis was performed to obtain the descriptive statistics of the variables. The independent variables were the following: live weight, LW (kg); daily weight gain, DWG (kg); dry matter intake, DMI (kg); fecal production (kg), in grams of CH₄ per day (CH₄gd), in kilograms of CH₄ per year (CH₄ky), in grams of CH₄ per kilograms of live weight (CH₄LW), in grams of CH₄ per kilograms of live weight gain (CH₄LWG), in grams of CH₄ per kilograms of dry matter intake (CH₄DMI); and net energy loss as CH₄ (YM), including the fixed effects of animal (ANI), collection period (PER), and treatment (TREAT). The collection period was considered as a measure repeated over time. Animal in treatment was considered as the random effect. The cumulative results and the analyses composed by the collection periods were considered taking into account the effects of treatment and period. The results obtained were subjected to analysis of variance, using the Mixed procedure of the software program SAS (SAS Institute Inc., 9.3, 2016). The Tukey's test of multiple means was applied to compare the treatments at 5% probability. The results of the forage samples were subjected to analysis of variance using the GLM procedure of the software program SAS (SAS Institute Inc., 9.3, 2016).

All the procedures performed in the present study followed the norms published by the National Council of Animal Experimentation Control (Concea), and were

approved by the Animal Research Ethics Committee (CEUA/UFPI) under the protocol No. 140/16.

Results and Discussion

A density of 67 trees ha⁻¹ in the silvopastoral system produced a shaded area of 7,604.4 m², which represented 26% of the total area of this sector. This level of shading has been deemed average by Paciullo et al. (2007), who observed that a 'Mombaça' grass shading of up to 35% allowed radiation to reach enough forage canopy for the forage development.

In the present study, the presence of trees improved forage quality, especially in the dry season (Table 1). In this period, (CP) and ether extract (EE) contents, digestibility of organic matter (DOM), and total digestible nutrients (TDN) were higher in the silvopastoral system than in the system under full sun, whereas DM, NDF, and TCHO were lower. These results were not observed in the rainy period, except for the higher-CP content and lower content of nonfiber and total carbohydrates in the silvopastoral system (Table 2).

Table 1. Chemical composition of forage (*Megathyrsus maximus* 'Mombaça') subjected to two treatments: under full sun, and in a silvopastoral system, in the dry period.

Variable (% of dry matter)	Treatments		Mean±Standard error of mean	Coefficient of variation (%)	p-value
	Sun	Silvopastoral			
Dry matter ⁽¹⁾	41.18	36.23	38.71±1.42	11.58	0.0909
Organic matter	90.44	90.06	90.25±0.28	0.97	0.5237
Crude protein	5.67	7.33	6.50±0.46	22.48	0.0665
Ether extract	1.50	1.90	1.70±0.1	17.98	0.0266
Neutral detergent fiber	66.44	64.00	65.22±0.68	3.29	0.0703
Acid detergent fiber	37.44	35.47	36.45±0.84	7.30	0.2653
Hemicellulose	29.00	28.54	28.77±0.74	8.13	0.7730
Nonfiber carbohydrates	16.83	16.82	16.82±0.63	11.87	0.9977
Total carbohydrates	83.27	80.82	82.04±0.57	2.21	0.0215
Phosphorous	0.12	0.13	0.12±0.01	21.85	0.5687
Calcium	0.46	0.49	0.48±0.03	22.19	0.7204
In vitro digestibility of dry matter	53.95	60.98	57.47±2.21	12.15	0.1151
In vitro digestibility of organic matter	49.79	57.74	53.76±2.40	14.09	0.0972
Total digestible nutrients	48.13	56.22	52.17±2.44	14.76	0.0971

⁽¹⁾Values (%) of fresh matter.

Table 2. Chemical composition of forage (*Megathyrsus maximus* 'Mombaça') subjected to two treatments: under full sun and in a silvopastoral system, in the rainy period.

Variable (% dry matter)	Treatments		Mean±Standard error of mean	Coefficient of variation (%)	p-value
	Sun	Silvopastoral			
Dry matter ⁽¹⁾	27.48	25.81	26.64±1.07	13.89	0.3156
Organic matter	90.66	90.65	90.65±0.31	1.17	0.9852
Crude protein	9.34	13.20	11.27±0.73	22.30	0.0025
Ether extract	1.93	1.91	1.92±0.09	16.97	0.8289
Neutral detergent fiber	63.52	64.37	63.94±1.07	5.79	0.2811
Acid detergent fiber	37.22	37.01	37.11±0.58	5.38	0.8653
Hemicellulose	26.30	27.36	26.83±0.92	11.96	0.4979
Nonfiber carbohydrates	15.87	11.18	13.52±1.23	31.60	0.0005
Total carbohydrates	79.38	75.54	77.46±0.91	4.05	0.0051
Phosphorous	0.22	0.20	0.21±0.02	31.45	0.4634
Calcium	0.39	0.36	0.37±0.03	28.55	0.5661
In vitro digestibility of dry matter	61.19	62.99	62.09±1.84	10.25	0.2025
In vitro digestibility of organic matter	58.18	60.09	59.14±1.95	11.42	0.1994
Total digestible nutrients	56.66	58.61	58.96±1.56	9.19	0.1984

⁽¹⁾Values (%) of fresh matter.

A lower-DM content in the silvopastoral system than in the full sun system was also observed by Rodrigues et al. (2016). These authors evaluated a 'Mombaça' grass pasture with 50/30 cm (that is, starting and ending heights in intermittent grazing) combined with babassu palms, versus a pasture under full sun. The lower content of DM in the silvopastoral system is probably associated with the higher-moisture content in the plants under shade, as a result of the milder microclimate around the trees, which reduces the evapotranspiration and keeps the plant more tender and succulent for longer (Sousa et al., 2007). The elevation of NDF content in the pasture under full sun may be associated with the higher proportion of sclerenchymatous tissue (Gobbi et al., 2011). Cells exhibit walls that are thicker under conditions of high luminosity than under shading conditions. Similar results have been obtained by Paciullo et al. (2007); these authors reported a TDN content decrease under moderate shading; however, they did not observe any effect on the ADF values.

The systems were separately compared in each period because of the great change that rainfall causes in the pasture. In both the dry and rainy periods, the CP content was higher in the silvopastoral system (Tables 1 and 2). This response is common in shaded pastures and is well described in the literature (Paciullo et al., 2007; Gobbi et al., 2011). According to Xavier et al. (2014), shade conditions lead to an increase of organic matter degradation and soil-nitrogen recycling, which favors an increase of protein level.

In the dry period, the CP values were critical in the pasture under full sun conditions (Table 1). However, the DM intake by the animals under full sun conditions was not limited (2.5% of LW). In the shaded pasture, the CP value of forage exceeded 7%, which allowed an intake of 3.6% of LW. An important factor in grazing-only, and therefore low-cost production systems is the type of animal used. The Curraleiro Pé-duro cattle are native to the Brazilian Semiarid Region and, for hundreds of years, have been adapted to surviving on feed with low-nutritional value, low-protein content, and high-fiber content (Carvalho et al., 2013). The fact that intake limitation and subsequent weight loss do not occur may be, therefore, a consequence of using these animals. This practice minimizes a major problem in Brazilian animal farming (the compromise of the production cycle, the waste of time and resources, and the occurrence of methane emissions without the production of meat, which, in general, increases emissions), in order to regain productivity in more favorable periods (Berndt & Tomkins, 2013).

In the dry period, the lower quantity of fibers and higher contents of CP and EE allowed an elevation of TDN contents in the shaded system, and positively affected organic matter digestibility, enabling a higher intake of forage in this system, and a lower emission of methane per kilogram of consumed DM (Table 3). These results are similar to those obtained in moderately shaded pastures by Paciullo et al. (2007), who also observed higher-CP values and lower NDF in the silvopastoral system, which led to an increase of digestibility.

Table 3. Variables of performance and enteric methane of crossbred cattle (Curraleiro Pé-duro x Nelore) subjected to two treatments: under full sun, and a silvopastoral system, in the dry period.

Variable ⁽¹⁾	Treatments		Mean±Standard error of mean	Coefficient of variation (%)	p-value
	Sun	Silvopastoral			
Live weight (LW, kg)	199.0	185.8	192.4±6.82	3.5	0.7693
Daily weight gain (DWG, kg)	0.137	0.194	0.166±0.02	12.0	0.6512
Dry matter intake (DMI, kg)	5.094	6.697	5.895±0.19	3.2	0.0028
Fecal production (kg)	2.34	2.61	2.48±0.08	3.2	0.3634
Emission of methane (CH ₄ gd, g per day)	120.6	124.4	122.5±4.66	3.8	0.9767
Emission of methane (CH ₄ ky, kg per year)	44.03	45.40	44.72±1.70	3.8	0.9768
CH ₄ LW (g kg ⁻¹)	0.616	0.678	0.647±0.03	4.6	0.6705
CH ₄ DWG (g kg ⁻¹)	1324	733.3	1029±204.8	19.9	0.5033
CH ₄ DMI (g kg ⁻¹)	24.29	18.66	21.48±1.07	5.0	0.0975
YM	7.77	5.81	6.79±0.34	5.0	0.0631

⁽¹⁾CH₄LW, emission of methane (g kg⁻¹) of live weight; CH₄DWG, emission of methane (g kg⁻¹) of daily weight; CH₄DMI, emission of methane (g kg⁻¹) of dry matter; YM, loss of gross energy as CH₄ (% of ingested gross energy).

The forage in the system under full sun had a higher quantity of total carbohydrates in both periods (Tables 1 and 2). This finding was also reported by Rodrigues et al. (2016), as they observed higher quantities of senescent material in the 'Mombaça' pasture under full sun than in the combination of pasture and babassu.

The increase of fibrous carbohydrates, observed in the dry period, represents a higher potential for enteric CH₄ emission because the fermentation of these compounds results in higher losses of gross energy than that of sugars and starch (Cota et al., 2014).

Methane emission in the dry period was similar between both systems, and was deemed low (Table 3). These values were lower than those presented by Dong et al. (2006), who estimated 56 kg CH₄ per year (Dong et al., 2006) in Brazilian calves for beef production. The intensity of methane emission is a result of the diet quality, the feed intake by animals, and the low-daily weight gain. The more the fiber content is in the forage, the lower will be the digestibility, and the higher will be the methane emission (Hart et al., 2009). During the dry period, forage had a high-amount of fibers; however, weight gain in this period was much lower than that in the rainy period. This was due to the low-nutritional value of the diet and the lower-dry matter intake, in the dry period, which led to a lower emission per animal.

The loss of gross energy per CH₄ (YM) differed between the two systems only in the dry period, and it was lower in the silvopastoral system (Table 3). This

means that, in this system, the energy contained in the food was better used because the diet probably had a higher level of energy, as a result of the higher EE and TDN contents (Table 1), which resulted in higher in vitro digestibility of organic matter and energy use (Table 3). No differences were observed between the two systems in the rainy period because of the higher availability of food to the animals in both systems (Table 4). This result may be related to the better quality of forage, namely to EE content, which represents a more energetic fraction of forage (Cota et al., 2014), that led to an increase of usable energy and DM intake. In general, the values of gross energy loss, in the form of CH₄ (YM), varied between 5.81 and 7.86% of the gross energy consumed in the diet. These values are similar to those obtained by Demarchi et al. (2016), and are close to those published by Dong et al. (2006), that is, a 6.5% loss for animals grazing on tropical forage (Tables 3 and 5).

The availability of forage was not affected by the type of pasture – silvopastoral and monoculture. The GFDM values were low, and the DFDM high for the dry period. In the rainy period, there was an increase of the development of forage, with improvements in the nutritional value, and the production of green mass, in both systems (Tables 2 and 4). In the rainy period, there was a better balance between the system under full sun and the silvopastoral system. In addition, there was an even higher content of CP, and a lower content of nonfiber and total carbohydrates in the silvopastoral

Table 4. Availability of forage (*Megathyrus maximus* 'Mombaça') subjected to two treatments: under full sun and in a silvopastoral system in the dry and rainy periods.

Variable	Treatments		Mean±Standard error of mean	Coefficient of variation (%)	p-value
	Sun	Silvopastoral			
Dry period					
Total forage dry mass (TFDM, kg ha ⁻¹)	2213.94	2320.35	2267.14±393.58	41.0	0.8352
Green forage dry mass (GFDM, kg ha ⁻¹)	929.16	1420.41	1174.79±227.15	40.3	0.3818
Green leaf lamina dry mass (GLLDM, kg ha ⁻¹)	460.18	868.44	664.31±141.84	38.3	0.1318
Green stem dry mass (GSDM, kg ha ⁻¹)	468.99	551.97	510.48±137.09	40.7	0.7988
Dead forage dry mass (DFDM, kg ha ⁻¹)	1284.77	899.94	1092.36±306.09	32.6	0.0861
Rainy period					
Total forage dry mass (TFDM, kg ha ⁻¹)	3252.08	2731.76	2991.92±345.41	35.9	0.4784
Green forage dry mass (GFDM, kg ha ⁻¹)	2877.18	2508.63	2692.90±246.38	31.6	0.4810
Green leaf lamina dry mass (GLLDM, kg ha ⁻¹)	2084.03	1779.39	1931.71±127.37	22.8	0.2496
Green stem dry mass (GSDM, kg ha ⁻¹)	793.15	729.23	761.19±141.40	40.3	0.8215
Dead forage dry mass (DFDM, kg ha ⁻¹)	374.90	223.13	366.27±105.73	31.0	0.3370

system. However, the values for digestibility and intake were similar between treatments (Table 5) as a result of the improved edaphoclimatic conditions, which enabled the pasture recovery, with an increase of the contents of CP, EE, TDN, IVDDM, and DOM. Similar findings were obtained by Euclides et al. (2009) and Demarchi et al. (2016). These authors observed variations in the nutritional value of the pastures over one year, with an improvement of forage quality as the abiotic factors (temperature, sunlight, and water) became more favorable.

The animal performance was similar between the evaluated systems during the rainy period, with a DM intake of more than 7 kg per day, corresponding to 3.4% of LW per day (Table 5). These values are higher than those obtained by Garcia et al. (2011) in the rainy period, in a pasture rotating with 'Mombaça' grass. They observed an intake of 3.2% of LW per day and gains of 0.850 kg per day in Limosin-Nellore calves. This confirms that it is possible to use the CPD-Nellore animals in the region, in a sustainable production system.

Enteric methane emissions increased in the rainy period, and there were no differences between the system under full sun and the shaded system. This increase was due to the good quality of the pasture and digestibility, which led to high-forage intake. However, emission intensity, CH₄DWG [kg of CH₄ per daily weight gain (kg of meat product)], was lower in the rainy period. Under full sun conditions, the value in the rainy period was approximately seven times lower

than that in the dry period and, in the silvopastoral system, the value was more than three times lower in the rainy period than in the dry period. Similar results were obtained by Demarchi et al. (2016), who studied the effect of the seasons on methane emissions by grazing Nellore cattle in Brazil. The highest emission was observed during the summer (220.91 g per day), followed by autumn (159.98 g per day), spring (132 g per day), and winter (102.49 g per day). These variations were related to the seasonal effect on the quality of forage, and variations of dry matter intake. Although methane emissions were higher in the summer, the authors observed lower emissions per kilogram of product in this season, as a result of the greater animal weight gain. This finding is in line with the results obtained in the present study because the higher emissions in the rainy period are a result of the high-forage intake and weight gain.

The increase of intake is a means of mitigating the generated emissions, by animal yield improvement. Therefore, the reduction of emissions will not occur per animal, but rather per kilogram of meat produced. This concept is shared by Hart et al. (2009), who observed that maximizing intake by improving pastures is a practical and inexpensive method of reducing CH₄ emissions by ruminants, thereby generating more meat per gram of emitted methane. Thus, low-cost systems that avoid weight loss in the critical period, and ensure sufficient quality feeding for the remaining months of the year, may contribute to mitigating these emissions.

Table 5. Variables of performance and enteric methane of crossbred cattle (Curraleiro Pé-duro x Nelore) subjected to two treatments: under full sun, and a silvopastoral system, in the wet period.

Variable ⁽¹⁾	Treatments		Mean±Standard error of mean	Coefficient of variation (%)	p-value
	Sun	Silvopastoral			
Live weight (LW, kg)	278.0	253.9	266.0±6.82	2.6	0.3420
Daily weight gain (DWG, kg)	1.150	0.958	1.054±0.07	6.6	0.4908
Dry matter intake (DMI, kg)	7.897	7.671	7.784±0.19	2.4	0.9367
Fecal production (kg)	3.08	2.84	2.96±0.08	2.7	0.4524
Emission of methane (CH ₄ gd, g per day)	192.8	203.3	198.0±4.66	2.4	0.6769
Emission of methane (CH ₄ ky, kg per year)	70.35	74.20	72.28±1.70	2.4	0.6788
CH ₄ LW (g kg ⁻¹)	0.697	0.803	0.750±0.03	4.0	0.2618
CH ₄ DWG (g kg ⁻¹)	175.2	214.8	195.0±9.98	5.1	0.2552
CH ₄ DMI (g kg ⁻¹)	24.74	26.50	25.62±1.07	4.2	0.8409
YM	7.62	7.86	7.74±0.34	4.4	0.9840

⁽¹⁾CH₄LW, emission of methane (g kg⁻¹) of live weight; CH₄DWG, emission of methane (g kg⁻¹) of daily weight; CH₄DMI, emission of methane (g kg⁻¹) of dry matter; YM, loss of gross energy as CH₄ (% of ingested gross energy).

Conclusions

1. The silvopastoral system provides an improvement of pasture quality, with the increase of protein content; in addition, in the dry period, the silvopastoral system provides higher ether extract and total digestible nutrient contents, lower-fiber content, and better digestibility of organic matter than the system under full sun conditions.

2. The animals in the system under full sun conditions and in the silvopastoral system emit similar amounts of methane during the same period.

3. Pastures with better quality and quantity of forage improve the animal performance, thereby reducing methane emissions per kilogram of beef produced.

4. Curraleiro Pé-duro x Nellore cattle exhibit good performance in both systems, and can be used for beef production in the region under the evaluated conditions.

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