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How canopy structural and morphological characteristics, and forage chemical composition affect a pasture-based dairy system?

Como as características estruturais e morfológicas do dossel, e a composição química da forragem afetam um sistema de produção de leite em pastagem?

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Highlights

Structural and morphological characteristics are more correlated with Mombasa grass.
Forages of erect growth have greater stem proportion in the forage mass.
Canopy structure characteristics are the main factors determining milk yield per area.

Abstract

Pasture-based systems are prevalent among small-scale family farms. Many farmers consider that the nutritional value of the plant is more relevant than the canopy structure. This study aimed to analyze the various factors related to plant structure and chemical composition that most influence milk yield per hectare under rotational stocking. The experiment was performed at the Animal Husbandry Experimental Station of the Extreme South of Bahia. Three rotational stocking systems with three forage species [*Cynodon dactylon* (L.) Pers. cv. Tifton 85, *Urochloa brizantha* (Hochst. ex A. Rich.) Stapf. cv. Xaraés, and *Megathyrsus maximus* Jacq. cv. Mombasa] were evaluated. Nine crossbred Holstein x Gyr cows were allocated to a balanced 3 x 3 Latin square design. The cows were rotated in three pastures every 14 days. The experimental period consisted of seven evaluation cycles of 42 days each. Cluster analysis, principal

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component analysis (PCA), and multivariate linear regression were the statistical techniques used to evaluate plant structure and morphological characteristics, and animal performance. Xaraés palisadegrass and Mombasa guinea grass were similar for all evaluated characteristics ($P > 0.05$), whereas Tifton 85 was different from them in terms of structural, morphological, and chemical composition characteristics ($P < 0.05$). In the PCA, 59.1% of the total variance was explained by components 1 and 2 for the structural and morphological characteristics, and forage chemical composition. Forage structural and morphological variables showed better results in the multivariate linear regression analysis for milk yield per hectare. Structural and morphological characteristics were more correlated with Mombasa guinea grass than Xaraés palisadegrass and Tifton 85. The structural and morphological characteristics of forages were the main factors determining milk yield per hectare in exclusively pasture-based systems with animals of low production.
Key words: *Cynodon.* Forage chemical composition. Grazing management. *Megathyrsus.* Urochloa.

Resumo

Os sistemas baseados em pastagens são predominantes entre os pequenos agricultores familiares. Muitos agricultores consideram que o valor nutricional da planta é mais relevante que a estrutura do dossel. Este estudo teve como objetivo analisar os vários fatores relacionados à estrutura da planta e a composição química que mais influenciam a produção de leite por hectare sob lotação rotativa. O experimento foi realizado na Estação Experimental de Pecuária do Extremo Sul da Bahia. Três sistemas de lotação rotacionada com três espécies forrageiras [*Cynodon dactylon* (L.) Pers. cv. Tifton 85, *Urochloa brizantha* (Hochst. Ex A. Rich.) Stapf. cv. Xaraés e *Megathyrsus maximus* Jacq. cv. Mombaça] foram avaliados. Nove vacas mestiças Holandês x Gir foram distribuídas em um quadrado latino equilibrado 3 x 3. As vacas foram rotacionadas em três pastos a cada 14 dias. O período experimental consistiu de sete ciclos de avaliação de 42 dias cada. Análise de cluster, análise de componentes principais e regressão linear multivariada foram as técnicas estatísticas utilizadas para avaliar as características estruturais e morfológicas das plantas e o desempenho animal. O capim-Xaraés e o capim-Mombaça foram semelhantes para todas as características avaliadas ($P > 0,05$), enquanto o Tifton 85 foi diferente em termos de características estruturais, morfológicas e de composição química ($P < 0,05$). Na PCA, 59,1% da variância total foi explicada pelos componentes 1 e 2 para as características estruturais e morfológicas, e a composição química da forragem. As variáveis estruturais e morfológicas das forrageiras apresentaram melhores resultados na análise de regressão linear multivariada para a produção de leite por hectare. Características estruturais e morfológicas foram mais correlacionadas com o capim-Mombaça do que para os capins Xaraés e Tifton 85. As características estruturais e morfológicas das forragens foram o principal fator determinante da produção de leite por hectare em sistemas baseados exclusivamente à pasto com animais de baixa produção.
Palavras-chave: *Cynodon.* Composição química da forragem. Manejo do pastejo. *Megathyrsus. Urochloa.*

Introduction

Milk production has great importance for Brazilian livestock farming. National dairy farming has evolved continuously, resulting in a steady growth in milk production over recent decades (Anuário Leite, 2018). National milk production almost quadrupled from 7.1 billion liters in 1974 to more than 35.1 billion liters in 2014, making Brazil the fourth-largest producer of milk in the world (Anuário Leite, 2018). Two production systems are predominant in the national scenario: pasture and free stall barn. Pasture-based systems are prevalent among small-scale family farms (Instituto Brasileiro de Geografia e Estatísticas [IBGE], 2018). Studying pasture-based milk production is relevant not only because it is the predominant system, but it also usually has low levels of productivity (Legrand, von Keyserlingk, & Weary, 2009).

The favorable climatic characteristics for forage production and land area contribute to the predominance of pasture-based systems in Brazil. The total area of grassland in the country is 159 million ha (IBGE, 2018), of which cultivated pastures represent approximately 70% of the total pasture area (IBGE, 2018). *Urochloa, Megathyrsus,* and *Cynodon* are the main genus of cultivated species (S. C. Silva, Sbrissia, & Pereira, 2015), but *Urochloa* spp. represents the most substantial proportion (85%) of cultivated pastures in Brazil (Jank, Barrios, Valle, Simeão, & Alves, 2014). Grasses of the genus *Megathyrsus* are alternative options to *Urochloa* for intensive livestock production in fertile areas due to its high production capacity (Maciel et al., 2018). Grasses of the genus *Cynodon*, as well as their intra- and inter-specific hybrids, are creeping grasses that spread either by stolons, rhizomes, or both (Silva et al., 2015) and are characterized by high nutritional value if adequately managed (Borges et al., 2017).

Research has sought to understand the interaction between each type of plant and the grazing animal (Provenza, Gregorini, & Carvalho, 2015), given the large number of forage genotypes available. The development of grazing management strategies based on pasture targets, particularly canopy height, has become an essential requirement for increasing livestock production and reducing the amount of land used (Rouquette, 2015; Silva et al., 2015). Thus, management strategies defined through research would allow substantial progress on many questions, which would provide conditions for better adjustments of current grazing management practices in Brazil (Congio et al., 2018; Gregorini et al., 2011; Muñoz et al., 2016). However, the adoption of grazing management practices by farmers is minimal. This fact, coupled with low adoption of technology, has resulted in low productivity per animal and per area (Martha, Alves, & Contini, 2012).

The canopy structure and forage nutritional value regulate forage intake in grazing ruminants (Fonseca et al., 2013). Forage intake is more affected by grazing management than nutritional value (Silveira et al., 2016). However, many farmers consider that the nutritional value of the plant is more relevant than canopy structure, leaving aside grazing management strategies (Allison, 1985; Rouquette, 2015). A typical case involves nitrogen fertilization in pasture management. Farmers are typically convinced that pastures fertilized with nitrogen will improve animal performance due to the higher nutritional value of the plant (Delevatti et al., 2019). However, increases in plant growth rate through fertilization will limit forage intake if grazing management practices are not adopted (Euclides et al., 2018; Geremia, Pereira, Paiva, Oliveira, & Silva, 2014).

Understanding the main factors affecting pasture-based production systems will help develop grazing management strategies to improve the structural characteristics of the plant and maximize animal performance. Therefore, we hypothesized that canopy structural and morphological characteristics have more influence on pasture milk production than forage chemical composition characteristics. Furthermore, forage plants with an erect growth habit have greater correlation with structural and morphological characteristics than forage with stoloniferous growth. This study aimed to evaluate the effect of structural, morphological, and forage chemical composition characteristics on milk yield per hectare in tropical grass pasture with different canopy structures.

Materials and Methods

Experiment study area

This experiment was performed at the Animal Husbandry Experimental Station of the Extreme South of Bahia (ESSUL) belonging to the Cocoa Research organization (CEPLAC/CEPEC) in the municipality of Itabela (16° 39′ S and 39° 30′ W, 918 m above sea level). According to Köppen's classification, the climate of the region is transitional between tropical rainforest climate (Af) and tropical monsoon climate (Am), with a mean annual rainfall of 1311 mm, and mean temperature of 25 °C (Peel, Finlayson, & McMahon, 2007). Meteorological data were obtained at a weather station located 1000 m southeast of the experimental area (Figure 1).

The soil in the area is an Acrisol (WRB/FAO classification) or a "Latossolo Amarelo Distrocoeso" according to the Brazilian classification (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2018). Soil texture is sandy at the surface, but clay content increases with depth from 160 (0–5 cm) to 250 g clay kg soil^{-1} (20–30 cm). Soil analyses were carried out using Embrapa standard techniques (Claessen, Barreto, Paula, & Duarte, 1997) and revealed the following properties: pH (H_2O) = 5.9; exchangeable Al, Ca, Mg, and K of 0.0, 1.9, 0.44, and 0.1 cmol$_c$ dm^{-3}, respectively; available P (Mehlich I) = 3 mg dm^{-3}.

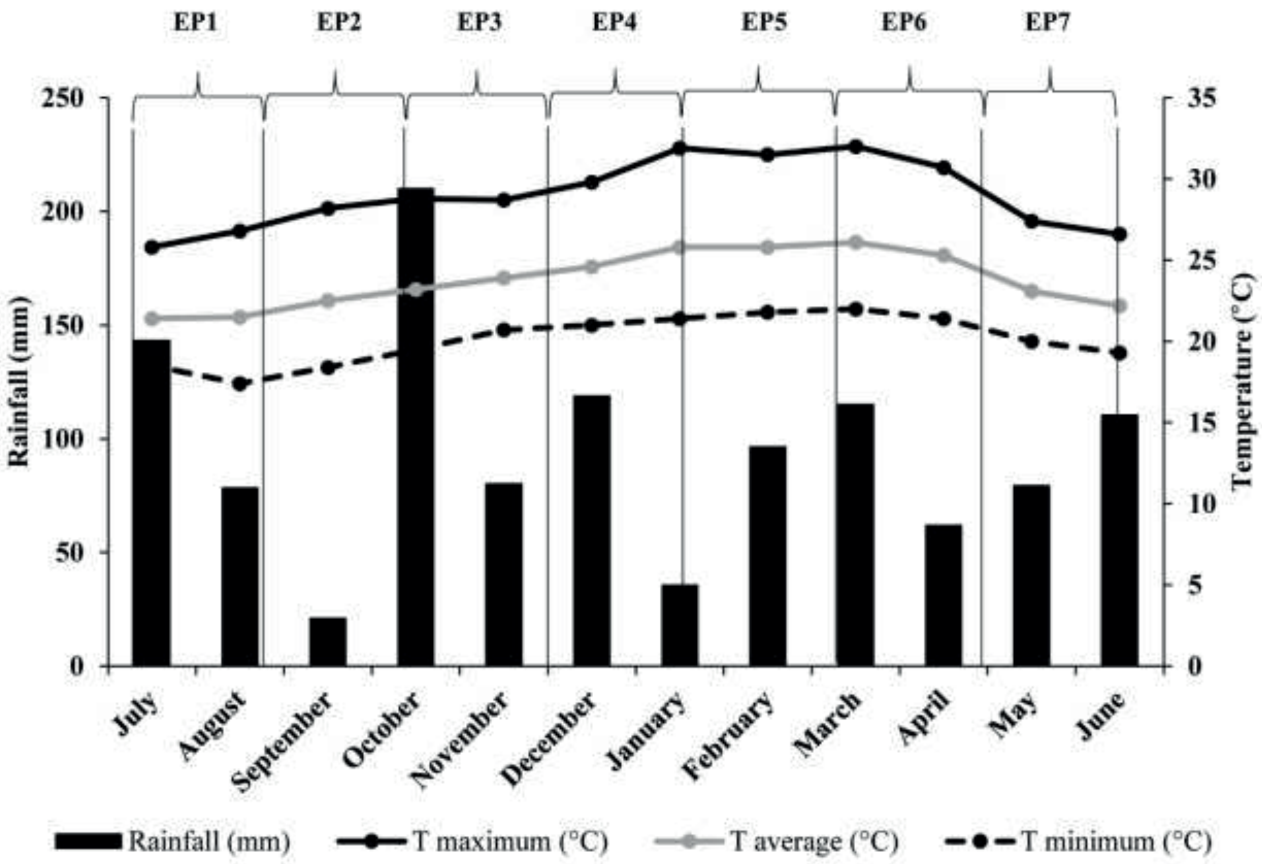

Figure 1. Mean monthly temperatures and rainfall in Itabela, South of Bahia, Brazil, during the experiment period.

Production system

Three rotational stocking systems with different forage species were evaluated in 2014 and 2015. For sowing, liming and phosphate fertilization were performed according to the soil analysis. A total of 1.5 tons ha^{-1} of dolomitic limestone and 450 kg ha^{-1} of single superphosphate fertilizer were applied to increase the base saturation to 70 and the phosphorus content to 25 mg dm^{-3}, respectively. The studied forages were *Cynodon dactylon* (L.) Pers. cv. Tifton 85 (Tifton 85), *Urochloa brizantha* (Hochst. ex A. Rich.) Stapf. cv. Xaraés (Xaraés palisadegrass), and *Megathyrsus maximus* Jacq. cv. Mombasa (Mombasa guinea grass). The experimental area with Tifton 85 was divided into 18 paddocks of 667 m^2, while areas with Xaraés palisadegrass and Mombasa guinea grass were divided into 28 paddocks of 429 m^2 each.

In rotational stocking systems, the paddocks are submitted to rest and grazing periods. Thus, for Tifton 85, the rest and grazing periods were 34 days and two days, respectively. For Mombasa guinea grass and Xaraés palisadegrass, the rest and grazing periods were 27 days and one day, respectively. The stubble height target was set to 60% of the pre-grazing canopy height (Fonseca et al., 2012). During a grazing cycle, put-and-take dry cows were used to adjust the stocking rate according to the criterion of maintaining stubble height target and grazing period.

Nitrogen and potassium fertilization were performed at the end of the grazing cycle using 300 kg N hectare^{-1} year^{-1} in the form of urea, and 240 kg K_2O hectare^{-1} year^{-1} in the form of potassium chloride, respectively. Fertilizer application was equally divided by the number of grazing cycles. Additionally, an irrigation system was used with sprinklers spaced 15 m apart from each other. Irrigation management was carried out on a supplementary basis with a six-day fixed watering shift and based on rainfall events, average air temperature, and evapotranspiration from data collected at the meteorological station.

Measurements

Canopy height and forage mass

The average canopy height was measured using a sward stick (Barthram, 1985) at 50 random points per paddock before (CHpre) and after grazing (CHpost). Forage mass (pre- and post-grazing) were sampled by using six frames of 1 × 0.5 m per paddock, once for each grazing cycle. After harvesting, the forage and morphological components were separated. Forage samples were separated into leaf (leaf blade), stem (stem + sheath), and senescent/dead material, and subsequently oven-dried at 55 °C for 72 h to a constant weight for determinations of pre- and post-grazing forage masses, leaf and stem masses (FMpre, LFMpre, SFMpre and FMpost, LFMpost, SFMpost, respectively). The difference in height and forage mass, and leaf and stem mass obtained in the pre- and post-grazing were used to calculate the grazing severity (GS; %); total, leaf, and stem disappearance rates in kilograms and percentage of pre-grazing mass (DF, LFMD, SFMD, %LFMD, %SFMD, respectively).

Chemical composition of the forage mass

Oven-dried samples of pre-grazing forage mass and leaves of each grazing cycle were ground in a Cyclotec mill (Tecator, Herndon, VA) to pass through a 1-mm screen. The dry matter (DM) of each sample was obtained by drying in an oven at 100 °C for 18 h (Association of Official Analytical Chemists [AOAC], 2000). The ash content was determined by incineration in a muffle furnace at 600 °C for 3 h (AOAC, 2000). The crude protein (CP) content was calculated based on the N concentration (CP = total N × 6.25), which was determined using the Kjeldahl procedure (AOAC, 2000). The lignin was analyzed according to method 973.18D (AOAC, 2000). The ash-free neutral detergent fiber (NDF) was determined sequentially by the autoclave method at 105 °C for 60 min (Pell & Schofield, 1993). The *in vitro* DM digestibility (IVDMD) was determined using the DAISYII method (Ankom Technology Corp., Fairport, NY) for 48 h (Holden, 1999). Rumen fluid was collected before feeding from two cannulated heifers fed a diet that consisted of *Urochloa* grass pasture fertilized with 150 kg of N ha^{-1} year^{-1} in the form of urea.

Animal performance

Nine crossbred Holstein x Gyr cows were allotted to a balanced 3 x 3 Latin square design and distributed in groups according to lactation period, as follows: cows with up to 75 days in milk, cows with 76–150 days milk, and cows with 151–225 days milk, being three cows of each lactation period. The cows were rotated in three pastures every 14 days. The experiment consisted of seven measurement periods in animals of 42 days each (the total period where the cows grazed all forage sources).

Milk yield (MY; kg cow^{-1} day^{-1}) was evaluated daily only from tester cows, which presented a MY of 8.1 ± 0.5 kg cow^{-1} day^{-1} before the experiment. The cows were milked once per day at 07:00 h without concentrate in the diet. Milk production from the first four days was ignored because groups of cows were rotated every 14 days in the three forage sources. The cows were weighed at the end of each grazing cycle. Based on the results of animal body weight (BW) and forage mass, the pre and post forage allowance (FApre and FApost; kg of forage mass kg BW^{-1}) were calculated. At the end of each grazing cycle, the stocking rate (animal unit [AU] ha^{-1}; AU was considered a cow weighing 500 kg according to Allen et al. (2011)) was calculated as the sum of BW of tester and "put-and-take" animals. The milk yield per hectare (MYH) of cows from each forage system was calculated by multiplying the daily milk yield by the average stocking rate of the system.

Statistical analysis

Three multivariate techniques were used for data analysis. Initially, clustering was performed on all studied variables using the nearest neighbor technique. The squared Euclidean distance was used to calculate the similarity matrix. Data were analyzed using the GLM procedure of SAS (SAS Institute, Cary NC). Means for forage traits were estimated using the LSMEANS procedure and compared by Fisher's protected least significant difference test with $P \leq 0.05$. The seven experimental periods were considered replications.

Multivariate analysis was carried out using the principal component analysis (PCA) method, generating a biplot graph with the prcomp functions from the *stats* package (R Core Team [R], 2018), and a *ggbiplot* from the ggbiplot package (Viu, 2011), together with the assistance of the *vegan* (Oksanen et al., 2018), *tidyverse* (Wickham, 2017), and *devtools* packages (Wickham & Chang, 2018).

The multivariate linear regression technique was used to generate conceptual models, in which the dependent variable chosen was MYH. Two simulations were performed, which generated four conceptual models. MYH was simulated with the structural and morphological characteristics + chemical composition characteristics, and vice versa. The best model was chosen based on the simplest and best represented MYH. The change of R^2 was used as the selection criterion. The comparisons between the predicted and real values were based on the significance of the regression between the two data sets (Mayer, Stuart, & Swain, 1994), residual analysis, accuracy (Cb) (Lawrence & Lin, 1989), the mean squared error of prediction (MSEP) (Bibby & Toutenburg, 1977), and the partition of sources of variation of MSEP (standard error of the mean, systematic error, and random error) (Theil, 1961). These statistics were calculated using the Model Evaluation System (MES, v.3.0.1, http://nutritionmodels.tamu.edu/mes.htm) (Tedeschi, 2006).

Results and Discussion

In the cluster analysis, Xaraés palisadegrass and Mombasa guinea grass were similar for all evaluated characteristics (Figure 2), whereas Tifton 85 was different from them in terms of structural, morphological, and chemical composition characteristics in all periods evaluated. These results highlight the importance of pasture management (Silva et al., 2015). These characteristics are genetically determined and are often related to the growth habit and morphophysiological traits of the plant (Castro-Montoya & Dickhoefer, 2020). Thus, while Xaraés palisadegrass, being a forage of the *Urochloa* genus, has its own grazing management targets, its growth habit is very similar to Mombasa guinea grass. This is likely the reason for Xaraés palisadegrass and Mombasa guinea grass being grouped together in the cluster analysis.

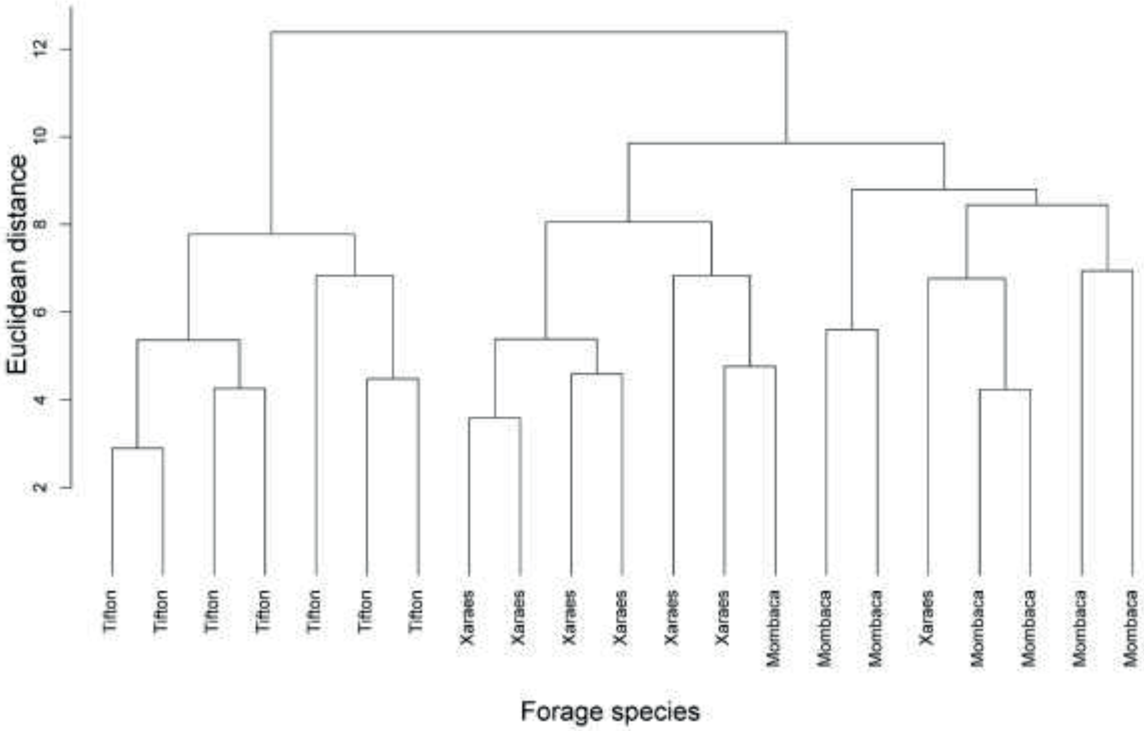

Figure 2. Cluster analysis of structural and morphological characteristics, and chemical composition of different forages.

Regarding the structural and morphological characteristics, CHpre, CHpost, FMpre, FMpost, LFMpre, LFMpost, SFMpre, and SFMpost were lowest in Tifton 85 pastures ($P < 0.001$; Table 1). The %GS was greater in Tifton 85 pastures (0.60 vs. 0.46 and 0.50 for the Xaraés and Mombasa pastures; $P = 0.014$). For disappearance of forage, the greater defoliation was observed in Mombasa guinea grass and Xaraés palisadegrass pastures ($P = 0.001$). There was no effect of forage species on LFMD and %SFMD ($P = 0.339$ and $P = 0.204$).

The greatest values for %LFMD and lowest for SFMD were observed in Tifton 85 pastures (P = 0.001 and P = 0.001, respectively). There was a significant effect of forage species on %LFMpre and %LFMpost (P = 0.019 and P = 0.021, respectively). The %LFMpre was greater and %LFMpost was lower in Tifton 85 than in Mombasa guinea grass and Xaraés palisadegrass. There was a significant effect of forage species on FApre and FApost (P < 0.001 and P < 0.001, respectively), with greater values for Mombasa guinea grass and Xaraés palisadegrass.

Mombasa guinea grass and Xaraés palisadegrass had greater forage mass and canopy heights in the pre and post conditions (Table 1). This greater forage mass is often associated with an increase in stem mass (Silva, Silva, Escobar-Guttiérrez, Lemaire, & Louarn, 2019). Mombasa guinea grass and Xaraés palisadegrass had a greater proportion of stem in the forage mass (8.0% and 12.0% more than Tifton 85, respectively). Forages with an erect growth habit develop structures to provide mechanical support to the aerial part of the plant (Silva et al., 2015), leading to increased plant height. Moreover, tropical grasses in monoculture managed for long rest periods are characterized by an increased proportion of stems in the upper stratum of the canopy (Silveira et al., 2016), limiting intake (Fonseca et al., 2012, 2013), which would also limit %GS. Besides, the greater stem contribution in the upper stratum of the canopy reduces the CP content and increases the NDF content of the canopy to be grazed (Gomes et al., 2018).

Table 1
Structural and morphological characteristics, and chemical composition of forage and animal productivity on Xaraés palisadegrass, Mombasa guinea grass and Tifton-85 pastures

Variable	Treatments			SEM	P-value
	Xaraés	Mombasa	Tifton-85		
Structural and morphological characteristics pre-grazing					
CHpre	55.8b	85.2a	34.2c	2.7	0.001
FMpre	4244a	4795a	1787b	236	0.001
LFMpre	1354a	1337a	713b	79.5	0.001
SFMpre	2889a	3459a	1074b	233	0.001
FApre	1.7a	1.9a	0.7b	0.09	0.001
Structural and morphological characteristics post-grazing					
CHpost	35.2b	48.7a	22.7c	1.3	0.001
FMpost	2273a	2370a	709b	138	0.001
LFMpost	633a	749a	147b	56.1	0.001
SFMpost	1640a	1622a	561b	123	0.001
FApost	0.90a	0.94a	0.28b	0.05	0.001

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Forage disappearance					
%GS	0.46b	0.50b	0.60a	0.02	0.008
DF	1970a	2425a	1078b	160	0.001
LFMD	721	588	566	79.9	0.339
%LFMD	0.52b	0.44b	0.78a	0.04	0.001
SFMD	1249b	1837a	512c	154	0.001
%SFMD	0.43	0.52	0.47	0.04	0.204
Forage chemical composition and digestibility					
Ash_{FM}	8.0b	8.9a	7.7b	0.32	0.027
OM_{FM}	92.0a	91.1b	92.3a	0.32	0.027
CP_{FM}	9.6b	9.9b	12.1a	0.73	0.001
NDF_{FM}	74.6a	70.8b	68.5b	1.1	0.009
Lig_{FM}	6.1	7.2	5.2	0.81	0.257
$IVDMD_{FM}$	59.7	58.3	57.8	1.5	0.532
$AshL_{FM}$	7.7b	9.0a	7.2c	0.24	0.001
OM_{LFM}	92.3c	90.9c	92.8a	0.24	0.001
CP_{LFM}	10.8b	11.0b	15.9a	1.1	0.008
NDF_{LFM}	72.3a	72.2a	64.8b	1.5	0.004
Lig_{LFM}	2.6	4.8	3.8	0.71	0.082
$IVDMD_{LFM}$	65.4	62.0	62.3	1.4	0.199
Animal productivity					
SR	5.2	4.6	4.5	0.39	0.217
MY	6.8	6.8	6.9	0.32	0.889
MYH	35.4	31.8	30.8	3.05	0.154

Pre- and post-grazing characteristics: canopy height (CHpre and CHpost, cm); forage mass (FMpre and FMpost, kg ha^{-1}); leaf forage mass (LFMpre and LFMpost, kg ha^{-1}); stem forage mass (SFMpre and SFMpost, kg ha^{-1}); forage allowance (FApre and Fa post, of the forage mass kg body $weight^{-1}$). Disappeareance of forage (DF, kg ha^{-1}), grazing severity (GS, %); leaf (LFMD, kg ha^{-1} and %) and stem (SFMD, kg ha^{-1} and %) disappearances rates; stocking rate (SR, AU ha^{-1}); milk yield (MY, kg cow^{-1} day^{-1}); milk yield per hectare (MYH, kg ha^{-1} day^{-1}). Chemical composition of the forage mass and leaf: crude protein (CP, %); organic matter (OM, %); in vitro dry matter digestibility (IVDMD, %); neutral detergent fiber (NDF, %); lignin (LIG, %).

[a-c]Least squares means within a row with different lowercase differ by Fisher's protected least significant difference (LSD) test at P ≤ 0.05.

For the chemical composition variables (Table 1), the values of ash content were lowest, and the organic matter content was greatest in Mombasa guinea grass (*P* = 0.001 and *P* = 0.001, respectively). Forage species did not affect IVDMD and lignin of leaves and forage mass (*P* = 0.199, *P* = 0.532, *P* = 0.082, and *P* = 0.257, respectively). Forage species significantly affected forage and leaf CP (*P* = 0.001 and *P* = 0.008, respectively) and NDF contents (*P* = 0.009 and *P* = 0.004, respectively). Greatest values of CP and lowest values of NDF were observed in Tifton 85 pastures and leaves. *Cynodon* species and cultivars, such as Tifton 85 are characterized by their higher nutritional value (Table 1) as a consequence of the greater proportion of leaves in the forage mass (Oliveira et al., 2011). Moreover, the greater proportion of leaves is associated with apprehension, resulting in greater %GS and %LFMD and lower value of %LFMpost in Tifton 85 canopy (Table 1).

There was no effect of forage species on MY, stocking rate, and MYH (*P* = 0.889, P = 0.217, and *P* = 0.154). The overall means for MY, stocking rate, and MYH were 6.8 kg cow^{-1} day^{-1}, 4.7 AU ha^{-1}, and 32.2 kg of milk-1 ha^{-1} day^{-1}, respectively. This is because grazing management is the main factor responsible for animal performance, where each forage species deserves adequate grazing management to express its potential (Rouquette, 2015; Silva et al., 2015). Evaluating two *Urochloa* species (pastures of Marandu and Mulato II) under the same rotational stocking target, Demski et al. (2019) reported that cows grazed on Mulato II grass had 7% more MY (15.2 kg cow^{-1} day^{-1}) compared to Marandu grass (14.1 kg cow^{-1} day^{-1}) and attributed this to the higher leaf:stem ratio and nutritive value of the Mulato II grass. The MY obtained in the current experiment was lower than that reported in pasture systems using tropical grasses such as elephant grass (*Pennisetum purpureum*), ranging from 14.1 to 16.7 kg cow^{-1} day^{-1} (Voltolini et al., 2010) and from 18.5 to 15.5 kg cow^{-1} day^{-1} (Congio et al., 2018), Mombasa guinea grass, ranging from 10.8 to 14.1 kg cow^{-1} day^{-1} (Hack et al., 2007), and Marandu and Mulato II grasses, ranging from 11.9 to 17.3 kg cow^{-1} day^{-1}. In all these studies, cows with greater MY potential were used. Thus, the animals received supplements to meet their nutritional requirements, receiving 1 kg of concentrate for each 3 kg of milk produced. In the current experiment, the cows were maintained on pasture without concentrate. On the other hand, the stocking rate obtained in the current study was close to that reported by Fukumoto et al. (2010), who obtained a mean stocking rate of 4.6, 4.5, and 5.0 UA ha^{-1} for Marandu, Tanzania (*Megathyrsus maximus* Jacq. cv. Tanzania^{-1}) and African star grass (*Cynodon nlemfuensis Vanderyst* cv. Estrela Africana), respectively.

In order to analyze the relationship between observed variables and summarize the results of the experiment, a PCA was performed (Figure 3). The PCA analysis (59.1% of the total variance was explained by components 1 and 2) showed clustering of a group of structural and morphological characteristics of pasture with high positive values in PC1 (44.8%) and average positive values in PC2 (14.3%). Therefore, these variables were closely related and included forage mass (FMpre and FMpost), canopy height (CHpre and CHpost), forage allowance (FApre and FApost), GS, and stem forage mass (SFMpre and SFMpost). This occurs because grazing management is required regardless of the stocking system used. Grazing strategies should be specific to each forage species, and canopy height is usually the main management criterion used (Silva et al., 2015). This was observed where CHpre and CHpost were grouped with other structural characteristics. Furthermore, Mombasa guinea grass had a greater correlation with these structural characteristics. Forages with high growth potential and erect growth habits need more attention concerning grazing management practice (Carnevalli, Congio, Sbrissia, & Silva, 2021; G. P. Silva et al., 2019; S. C. Silva, Uebele, Congio, Carnevalli, & Sbrissia, 2021).

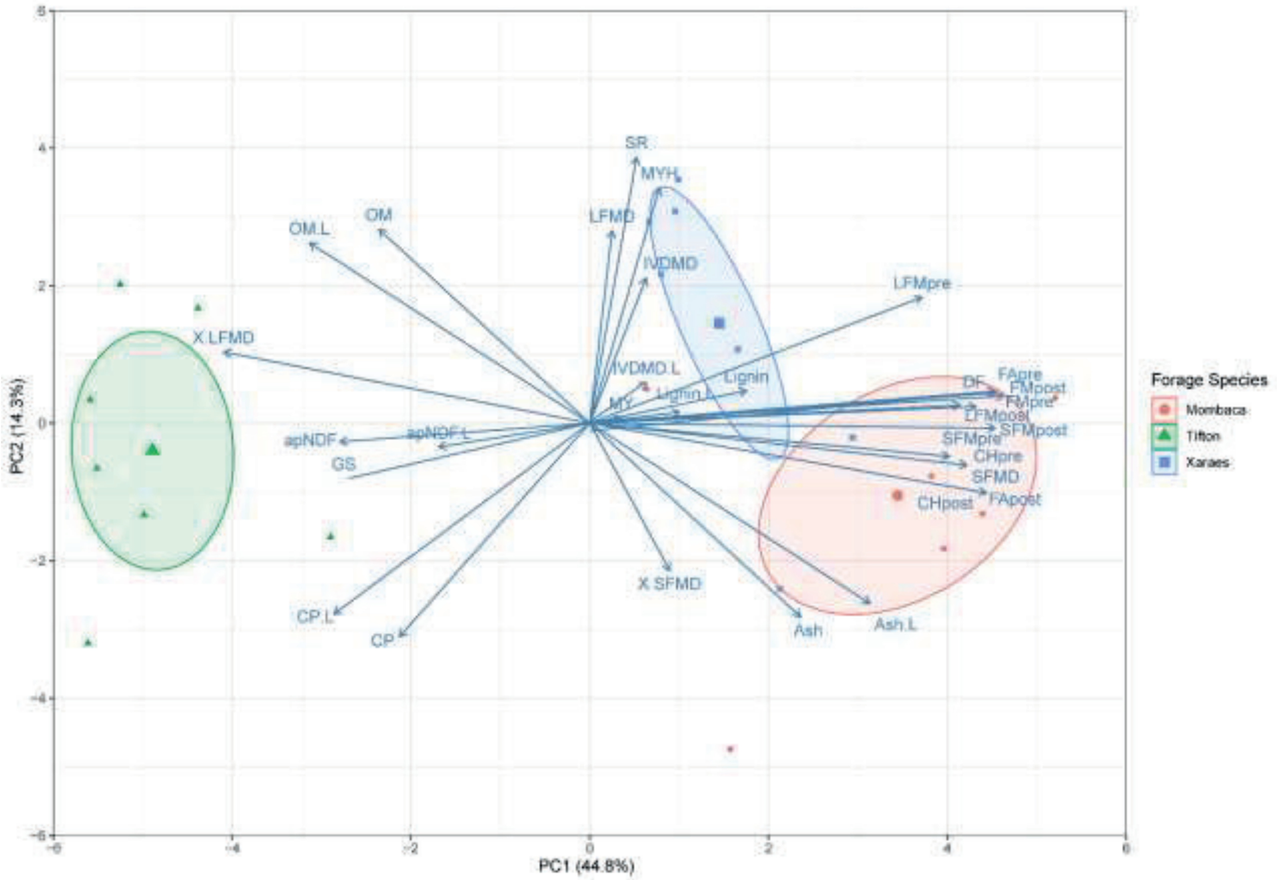

Figure 3. Principal component analysis. Pre- and post-grazing characteristics: canopy height (CHpre and CHpost, cm); forage mass (FMpre and FMpost, kg ha^{-1}); leaf forage mass (LFMpre and LFMpost, kg ha^{-1}); stem forage mass (SFMpre and SFMpost, kg ha^{-1}); forage allowance (FApre and Fa post, kg of forage mass kg body weight^{-1}). Disappeareance of forage (DF, kg ha^{-1}), grazing severity (GS, %); leaf (LFMD, kg ha^{-1} and %) and stem (SFMD, kg ha^{-1} and %) disappearances rates; stocking rate (SR, AU ha^{-1}); milk yield (MY, kg cow^{-1}); milk yield per hectare (MYH, kg ha^{-1} day^{-1}). Chemical composition of the forage mass and leaf: crude protein (CP, %); organic matter (OM, %); in vitro dry matter digestibility (IVDMD, %); neutral detergent fiber (NDF, %); lignin (LIG, %).

In the PCA analysis, to interpret each principal component, it should examine the magnitude and the direction of the coefficients of the original variables. The variables, leaf organic matter, forage mass organic matter, and %LFMpre were grouped with negative values in PC1 and average positive values in PC2. In the PC2 axis, the stocking rate, LFMD, forage IVDMD, and leaf IVDMD were closely associated with positive values in PC2. Some variables associated with the forage chemical composition (forage and leaf CP and NDF contents) and %GS were grouped with negative values in PC2 and PC1 (in the right quadrant and inferior part of PCA plot). Forage and leaf ash and %SFMD were grouped with positive values in PC1 and negative values in PC2 (Figure 3). These characteristics were more correlated to Tifton 85, which as previously discussed is a species of the *Cynodon* genus shown to have a greater forage nutritive value than Mombasa guinea grass and Xaraés palisadegrass (Oliveira et al., 2011).

The multivariate analysis provided a multidisciplinary understanding of variables that affected the MYH. In the multivariate linear regression analysis, the objective was to contrast the structural, morphological, and chemical composition variables selected in the PCA with MYH. Four conceptual models were developed (Table 2). The contribution of chemical composition variables in changing the coefficient of determination (R^2) was lower compared with structural and morphological variables in both the first (model 2) and second (model 3) simulation (0.004 and 0.427, respectively). The same was observed for the change of significance of "F," which was not significant (P = 0.093 and P = 0.105, respectively). Structural and morphological variables showed better results in both simulations (0.988 and 0.984 for models 1 and 4, respectively). Thus, model 1 had the most significant R^2 change, providing a reasonable estimate, with an R^2 = 0.989 (Figure 4). The distribution of the MSEP of the model was 0.17%, 0.35%, and 99.47%, corresponding to the mean error, systematic error, and random error. Moreover, the hypothesis tested to fit the conceptual model to the first-degree equation showed no significant difference (H0: $\beta 0 = 0$, P = 0.772; H0: $\beta 1 = 1$, P = 0.788). This indicates that the observed MYH data are identical to the data estimated by the model.

Table 2
Multivariate linear regression technique used to generate conceptual models in which the dependent variable used the milk yield per hectare (MYH)

Model Summary								
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	Sig. F Change	Durbin-Watson
1	0.996	0.992	0.988	0.844	0.992	286.932	0.000**	2.146
2	0.998	0.996	0.991	0.723	0.004	2.372	0.093	
3	0.653	0.427	0.236	6.924	0.427	2.234	0.105	2.201
4	0.997	0.995	0.984	0.986	0.568	91.488	0.000**	

* $P < 0.05$; ** $P < 0.001$.
The composition of the model are the variables: Model 1: structural and morphological characteristics only; Model 2: structural and morphological characteristics more chemical composition characteristics; Model 3: chemical composition characteristics only; Model 4: chemical composition characteristics more structural and morphological characteristics.

Grazing management modulates the canopy structure, which has an important effect on the process of forage harvesting during grazing (Benvenutti, Pavetti, Poppi, Gordon, & Cangiano, 2016). This experiment has shown that structural and morphological characteristics have more influence on MYH than the chemical composition of forage mass. Canopy structure and morphological components have been identified as critical attributes for the management of grazing systems due to their strong influence on bite dimensions. The greatest intake rate in canopies with greater leaf proportion than stem in the grazing stratum is due to a greater bite mass associated with a faster bite rate (Carvalho et al., 2015; Guzatti et al., 2017). Furthermore, in pastures with predominant upper strata of leaves, the bite area is maximized due to the benefits of tongue movement to grasp forage (Benvenutti et al., 2016). On the other hand, in canopies with a greater presence of stem at the top strata, the bite area is limited since the shearing force of the stem is elevated (Baumont, Cohen-Salmon, Prache, & Sauvant, 2004; Gregorini et al., 2011). Thus, forage intake is the main factor determining the productive performance of grazing animals (Carvalho et al., 2015).

There was no difference among forage sources for MY in the current experiment, which may suggest that the forage intake was similar among treatments. Even in pastures with different forage masses (like in the current experiment), the animals may have a similar forage intake when these pastures are managed under the same grazing management targets (Homem et al., 2021a,b). In pasture with greater forage mass, the bite mass will likely be greatest, and the grazing time will reduce. Conversely, the bite mass will likely be lower, and the grazing time will increase in pasture with lower forage mass when managed under the same grazing management targets (Homem et al., 2021a,b). Furthermore, grazing management targets allow stocking rate adjustments, which impact the enhancement of area production. Therefore, independent of the forage utilized, an adequate grazing management target should be used to achieve greater animal production.

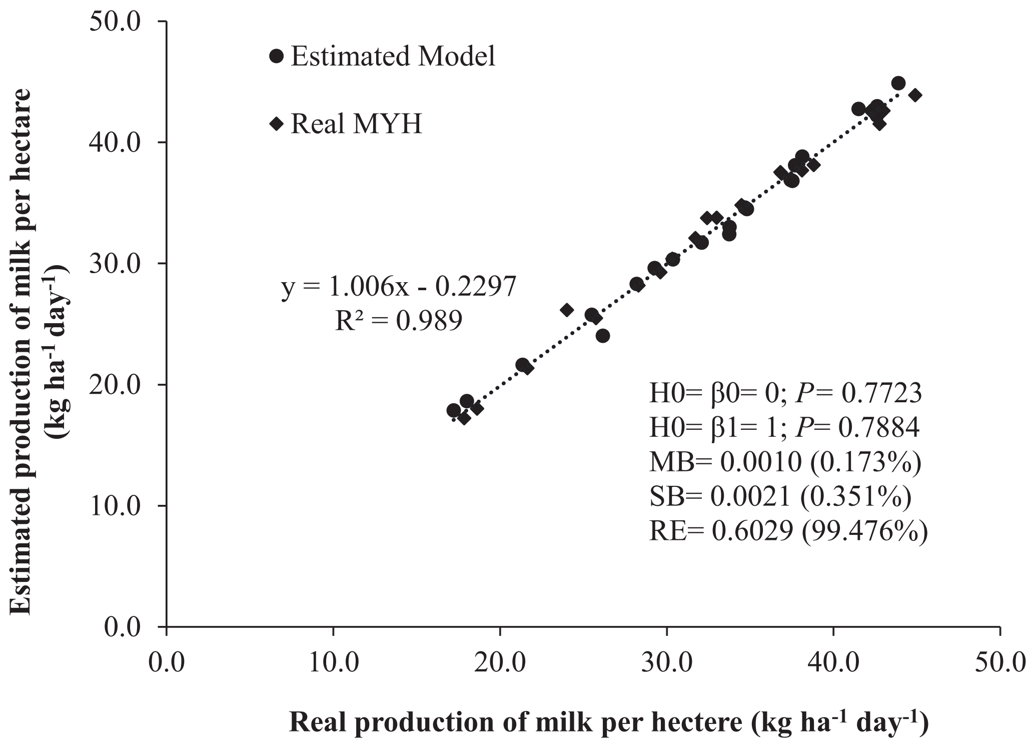

Figure 4. Comparison between the predicted values in the conceptual model 1 with real values of milk yield per hectare. MYH: Milk yield per hectare; MB: mean bias; SB: systematic bias; RE: random errors.

Conclusion

The forage species studied had different structural and morphological characteristics, and chemical compositions. Structural and morphological characteristics are more correlated with Mombasa guinea grass than Xaraés palisadegrass and Tifton 85. The structural and morphological characteristics of forages are the main factors determining milk yield per hectare, and are most correlated with animal-related variables in exclusively pasture-based systems with animals of low production. The forage chemical composition characteristics did not improve the milk yield per hectare estimation model in the current experiment.

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