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Forage production, morphogenetic and structural components, and nutritional value of tropical grasses in the semiarid condition

Produção de forragem, componentes morfogênicos e estruturais e valor nutricional de gramíneas tropicais em condição semiárida

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Highlights

Some cultivars of Urochloa and Megathyrsus adapt better to semiarid conditions.
Cultivars Marandu and Piatã had higher forage mass and water use efficiency.
Cultivar Kennedy had the highest TDN and DMD values.

Abstract

The objective of this study was to evaluate the forage mass, morphogenetic and structural characteristics, and nutritional value of tropical forage grasses in semiarid conditions. Nine grasses were evaluated, namely, three cultivars of *Urochloa brizantha* (Marandu, MG4, and Piatã); *Urochloa decumbens* cv. Basilisk; *Urochloa humidicola* cv. Llanero; *Urochloa ruziziensis* cv. Kennedy; and three cultivars of *Megathyrsus maximum* (Massai, Mombaça, and Tanzania). The experiment was laid out in a randomized complete block design in a split-plot arrangement in which the main factor were the grass cultivars and the secondary factor the seasons, with five replications per treatment. The statistical model included the fixed effect

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of treatment (grass), whereas the season was included as a random effect within treatments. *Urochloa brizantha* cvs. Marandu, MG4, and Piatã and *Urochloa decumbens* cv. Basilisk produced on average 858 kg ha^{-1} more forage mass than cvs. Kennedy and Basilisk. *Megathyrsus maximum* cv. Mombaça produced 40% more forage mass than the other cultivars of *M. maximum* (4205 vs. 3001 kg ha^{-1}). *Urochloa ruziziensis* cv. Kennedy showed the lowest water use efficiency (36%). *Urochloa ruziziensis* cv. Kennedy exhibited the lowest leaf weight among the Urochloa cultivars (740 vs. 1319 kg ha^{-1}). There was no treatment effect for leaf weight in the *M. maximum* cultivars. *Urochloa ruziziensis* cv. Kennedy showed the highest values of total digestible nutrients and dry matter digestibility (1.84 and 2.34%, respectively) among the other Urochloa cultivars. The *M. maximum* cultivars showed little differences in nutritional values. Cultivars Marandu, Piatã, and Massai exhibited better productive responses in the edaphoclimatic conditions of this study. However, future studies must be conducted evaluating the adaptation of the forage grass under semiarid conditions. Considering the settings of this study, the grasses *Urochloa brizantha* cvs. MG4, Marandu, and Piatã, as well as *Megathyrsus maximum* cvs. Massai and Mombaça, can be used in the semiarid condition.

Key words: Forage grass. *Megathyrsus maximum.* Productivity. *Urochloa.* Water stress.

Resumo

O objetivo deste estudo foi avaliar a produtividade, características morfogênicas e estruturais e valor nutritivo de gramíneas forrageiras tropicais em condições semiáridas. Nove gramíneas foram avaliadas: Três cultivares de *Urochloa brizantha* (Marandu, MG4 e Piatã), *Urochloa decumbens* cv. Basilisk, *Urochloa humidicola* cv. Llanero, *Urochloa ruziziensis* cv. Kennedy e três cultivares de *Megathyrsus maximum* (Massai, capim-Mombaça e Tanzânia). O experimento foi conduzido em blocos completos casualizados em esquema de parcelas subdivididas com o fator principal (cultivar) e o fator secundário (estação) com cinco repetições por tratamento. O modelo estatístico incluiu o efeito fixo de tratamento (cultivar), e a estação do ano foi incluída como efeito aleatório dentro do tratamento. *Urochloa brizantha* cv. Marandu, MG4 e Piatã e Urochloa decumbens cv Basilisk produziram em média 858 kg ha^{-1} de massa de forragem a mais que a cv. Kennedy e Llanero. Megathyrsus cv. Mombaça produziu 40% (4205 vs. 3001 kg ha^{-1}) a mais de massa de forragem do que as demais cultivares de *Megathyrsus maximum. Urochloa ruziziensis* cv. Kennedy apresentou a menor (36%) eficiência no uso da água (EUA). *Urochloa ruziziensis* cv. Kennedy produziu menor quantidade de folhas (740 vs. 1319 kg ha^{-1}) para as demais cultivares de *Urochloa.* Não houve efeito do tratamento na produtividade de folhas para as cultivares *Megathyrsus maximum. Urochloa ruziziensis* cv. Kennedy apresentou os maiores valores de nutrientes digestíveis totais (NDT) e digestibilidade da matéria seca (DMS) (+1,84 e 2,34%, respectivamente) em relação à outra cultivar de *Urochloa.* As cultivares *Megathyrsus maximum* tiveram pouco efeito sobre os valores nutritivos. As cultivares Marandu, Piatã e Massai apresentaram melhores respostas produtivas nas condições edafoclimáticas deste estudo. No entanto, estudos futuros devem ser realizados avaliando a adaptação da forrageira em condições semiáridas. Nesta condição de estudo, as gramíneas *Urochloa brizantha* cv. MG4, Marandu e Piatã, assim como o *Megathyrsus maximum* cv. Massai e Mombaça podem ser usados em condições semiáridas.

Palavras-chave: Gramíneas forrageiras. *Megathyrsus maximum.* Produtividade. *Urochloa.* Estresse hídrico.

Introduction

The semiarid climate is characterized by irregular rainfall, which is strongly concentrated in a short period of the year (Schmidt et al., 2018) and can reach up to 700 mm per year (Instituto Nacional de Meteorologia [INMET], 2019). These conditions effectively affect agricultural activities, mainly forage production (Simeão et al., 2021).

Pasture-based production is the most representative livestock farming system in Brazil, which involves the use of pastures as the main source of feed for ruminants. However, due to the above-described climatic conditions, production systems operate under limiting factors-one of the most important of which is the fluctuation of forage production throughout the year. This problem greatly affects semiarid regions, impacting plant production and, consequently, animal production.

Brazilian pastures are largely composed of grasses belonging to the gender *Urochloa (Brachiaria)* and *Megathyrsus (Panicum) maximum.* Due to their adaptation to the edaphoclimatic characteristics of the country (Fonseca & Martuscello, 2010), these species can also be used in semiarid conditions. Nevertheless, few studies have been developed to examine the production and morphological and structural characteristics of different cultivars, particularly *M. maximum* (Macedo et al., 2022) or *Urochloa* species under semiarid conditions (Rodrigues et al., 2021). Rodrigues et al. (2021) evaluated the forage mass of five *Urochloa* cultivars (Marandu, Piatã, Xaraés, Basilisk, and Paiaguás) and observed no statistical differences between the cultivars in a semiarid condition. Costa et al. (2021) also observed no statistical differences in forage mass between six *M. maximum* cultivars in a semiarid condition. However, little research has been done on the intrinsic characteristics of water use efficiency of *Megathyrsus* or *Urochloa* in semiarid conditions (Beloni et al., 2018; P. M. Santos et al., 2013).

In addition, understanding the physiological limits of the plant in the environment to which it is subjected is important to assess whether it can thrive and produce under adverse periods and environments. According to Staniak and Kocón (2015), plants in semiarid environments tend to develop adaptations to tolerate low rainfall and, most importantly, to improve functioning in terms of transpiration. Basic knowledge about the ecophysiological responses and morphogenesis of tropical forage grasses under semiarid conditions is important, as it can aid in the proper management of these species when used in regions with low rainfall. Our hypothesis is that different cultivars of *Urochloa* or *Megathyrsus* could have distinct tolerance to low water availability, changing their productive, morphological, and structural characteristics. Therefore, this study proposes to examine the productive potential, structural characteristics, and nutritional value of tropical forage grasses of the genera *Urochloa* and *Megathyrsus* in a semiarid condition.

Materials and Methods

The experiment was conducted between November 2018 and June 2019 in the experimental field of Southwestern Bahia State University, located in Itapetinga

- BA, northeast region of Brazil (15°38′46″ S, 40°15′24″ W, 280 m above sea level). According to the Köppen classification, the climate is classified as hot humid and sub-humid (CW type). Figure 1 shows the water balance (Thornthwait & Mather, 1955), temperature, and rainfall data collected during the experimental period (INMET, 2019).

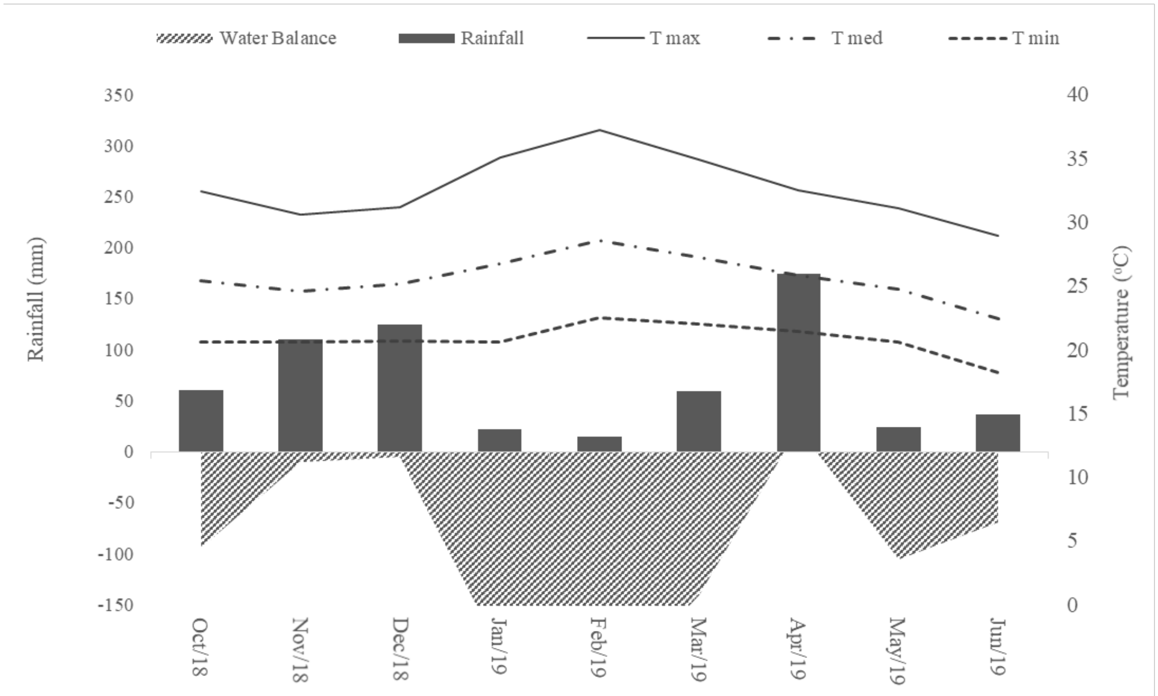

Figure 1. Maximum, minimum, and average temperatures, precipitation and monthly water balance from October 2018 to June 2019.

According to the Brazilian Agricultural Research Corporation, the soil is classified as Red Yellow Podzolic (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2006), with a weak sandy texture. Before sowing, the soil was prepared by plowing and harrowing. The need for fertilization was determined based on the results of chemical analysis of the soil samples; accordingly, 70 kg ha^{-1} of P_2O_5 and 20 kg ha^{-1} of K_2O were applied and the nitrogen fertilization level was established at 100 kg ha^{-1}. These were performed following the recommendations of the Comissão de Fertilidade do Solo do Estado de Minas Gerais [CFSEMG] (1999).

The treatments tested in the study were the species themselves, which consisted of nine grasses (six of the genus *Urochloa* and three of the genus *Megathyrsus*), namely, *U. brizantha* cvs. Marandu, MG4, and Piatã; *U. decumbens* cv. Basilisk; *U. humidicola* cv. Llanero; *U. ruziziensis* cv. Kennedy; and *M. maximum* cvs. Massai, Mombaça, and Tanzânia. The species were distributed in a randomized block design with five replications, across 16-m^2 (4 × 4 m) plots, with 1 m spacing between blocks.

For the implementation of the experimental site, all grasses were sown on

November 1, 2018, and on December 21, 2018. The uniformity cut was made in all plots to start the evaluations, which were carried out when the plants reached harvest height. Pre- and post-mowing heights were measured according to the particularities of each species. The pre/post-mowing heights were as follows: 30/15 cm for cvs. Basilisk, Llanero, and MG4; 35/20 cm for cvs. Marandu, Ruziziensis, and Piatã; 55/25 cm for cv. Massai; 70/35 cm for cv. Tanzania; and 90/45 cm for cv. Mombaça (Fonseca & Martuscello, 2010; Brazilian Agricultural Research Corporation (EMBRAPA, 2001) (Table 1). Canopy height was measured using a centimeter ruler, at the curvature of the leaves.

Table 1
Harvest cycles and evaluation of the forage mass of the grasses

	Harvest cycle			
Grasses	1° cycle	2° cycle	3° cycle	4° cycle
Basilisk	yes	yes	yes	yes
Llanero	yes	yes	yes	yes
MG4	yes	yes	yes	yes
Marandu	yes	yes	yes	yes
Piatã	yes	yes	yes	yes
Kennedy	yes	yes	yes	yes
Massai	yes	yes	yes	yes
Mombaça	yes	yes	yes	No
Tanzania	yes	yes	yes	no

[I]Basilisk: *Urochloa decumbens* cv. Basilisk; Lanero: *Urochloa humidicola* cv. Llanero; MG4: *Urochloa brizantha* cv. MG4; Marandu: *Urochloa brizantha* cv. Marandu; Piatâ: *Urochloa brizantha* cv. Piatã; Kennedy: *Urochloa ruziziensis* cv. Kennedy; Massai: *Megathyrsus maximum* cv. Massai; Mombaça: *Megathyrsus maximum* cv. Mombaça; Tanzania: *Megathyrsus maximum* cv. Tanzania.

For the analysis of forage mass (above the stubble), two samples were collected by throwing a 1-m^2 square frame over the usable area of the plot. The samples were cut observing the stubble height of each forage. Then, tiller density was determined by placing a 0.04-m^2 square frame within the larger square, to count the live tillers in the area.

In the samples collected for the determination of forage mass, the leaf:stem ratio was determined by dividing the different morphological components into leaf, stem + sheath, senescent material, and inflorescence. Subsequently, the samples were dried in a forced-air oven at 55 °C. Dried forage samples were ground (Wiley mill; A. H. Thomas, Philadelphia, PA, USA) through a 1mm screen sieve for chemical analysis.

Light interception (LI) and leaf area index (LAI) were evaluated using an electronic ceptometer (Accupar PAR/LAI LP-80, Decagon Devices, Inc., Pullman, USA), taking three readings above and below the canopy in each experimental unit (Rodrigues et al., 2014). The LI and the LAI values corresponded to the average of the obtained readings. Chlorophyll SPAD measurements were performed using the Minolta SPAD instrument (SPAD-502 Plus Chlorophyll Meter, EnviroMonitors®, Ford Lane Business Park, USA). Quantification was always performed around 10h00, at three points in the usable area of the plot, in fully expanded leaves, avoiding the midrib (Minolta, 1989).

To determine the relative water content (RWC), two fully expanded leaves were collected before dawn. In the laboratory, the central vein of the leaves was removed with scissors and cut into a square, around 1 cm on each side. Then, the material was weighed to determine the fresh weight (FW). To obtain the saturated weight (SW), the material was placed on glass plates, immersed in distilled water for 6 h at 4 °C, and weighed. The dry weight (DW) was obtained after oven-drying the samples at 60 °C until constant weight. These data were then used to calculate RWC, as proposed by Larcher (2000): RWC (%) = [(FW - DW) / (SW - DW] × 100.

Water use efficiency (WUE) was estimated by dividing forage mass by the amount of rainfall accumulated during the cycle until the moment of harvesting (Souza et al., 2016). The leaf water potential was measured in healthy tillers with fully expanded leaves using a Scholander pressure bomb (Model 1000, Tecnal®, Piracicaba, SP, Brazil). In this procedure, the leaves are placed in the instrument and a valve allows the control of the flow of compressed Nitrogen (N_2) that enters the chamber while a manometer coupled to the system allows the measurement of the pressure exerted during the entire process in bars (BAR), which are converted to Megapascal (MPa). During the analysis, it was necessary to observe sap exudation in response to the pressure exerted inside the chamber.

Stomatal conductance was evaluated between 10h00 and 12h00, using a leaf porometer (Decagon Devices SC-1, Meter®, São José dos Campos, SP, Brazil), at three different points in the usable area of the plot, in fully expanded leaves, avoiding the central vein.

Morphological and structural traits and tissue flow (growth and senescence rates) were assessed using the marked-tiller technique (Davies, 1988), by marking five random tillers with colored ribbons in each paddock. Measurements were performed every seven days throughout the experimental period until the moment of cutting, adopting the interval of leaf appearance rate (Pereira et al., 2019; Silva et al., 2009). The following variables were measured in each tiller: leaf length and width, stem length, and leaf lifespan.

With the above-mentioned data, it was possible to calculate the following variables: leaf elongation rate (LER, cm tiller^{-1} day^{-1}) - the increase in the length of the leaf blade between consecutive evaluations; stem elongation rate (SER, cm tiller^{-1} day^{-1}) - the increase in stem length between consecutive evaluations; leaf appearance rate (LAR) - the interval between the number of leaves per tiller and number of days in the evaluation period; phyllochron (days) - the inverse of leaf appearance rate; leaf lifespan (LLS, days) - time interval from the appearance of a leaf to its death, estimated by the equation proposed by Lemaire and Chapman (1996), as follows LLS = number of live leaves × Phyllochron.

Dry matter (DM; method 942.05), crude protein (CP; method 990.03), and ash (method

942.05) contents were determined according to the methodology of the Association of Official Analytical Chemists [AOAC] (2012). Neutral detergent fiber corrected for ash and protein (NDFap) and acid detergent fiber (ADF) were determined according to Van Soest et al. (1991). The total digestible nutrient (TDN) contents were estimated using the following equation described by Cappelle et al. (2001): TDN = 83.79 - 0.4171NDF. Dry matter digestibility (DMD) was estimated by the equation DMD = 88.9 - 0.779ADF, described by Castro et al. (2007).

The experiment was laid out in a randomized complete block design with five replications per treatment. Due to the great difference between the grass genera (*Urochloa* and *Megathyrsus*), they were analyzed separately. Data were analyzed using SAS software (Statistical Analysis System Institute [SAS Institute], 2012) version 9.3. The normality of the residues and the homogeneity of variances were examined for each continuous dependent variable analyzed after model fitting. All data were analyzed using the MIXED procedure of SAS. The Kenward-Roger method was used to calculate the approximate denominator degrees of freedom. The statistical model included the fixed effect of treatment (cultivar grass), and the block was included as a random effect within the treatment, as follows:

$$Y_{ij} = \mu + G_i + B_j + \varepsilon_{ij},$$

where Y_{ij} is the dependent variable; μ is the mean of the overall effect; G_i is the effect of grass; B_j is the effect of block; and ε_{ij} is the error associated with each observation. All results were reported as least square means. Significance was declared when $P \leq 0.05$.

Results and Discussion

Forage mass differed between the *Urochloa* grasses ($P < 0.01$). Water availability had a direct impact on this variable (Habermann et al., 2021; Giridhar & Samireddypalle, 2015; Zandalinas et al., 2018). The lower forage mass production of *U. ruziziensis* cv. Kennedy is explained by the lower WUE of this cultivar. The other *Urochloa* cultivars produced more forage mass and, accordingly, showed higher WUE. Contrary to the results of the present study, Beloni et al. (2018) evaluated three *Urochloa* cultivars (Marandu, Paiaguás, and Basilisk) and observed an increase in forage production when WUE was lower. Another factor involved in the difference in productivity between the cultivars is the specific characteristics of each type of grass, especially regarding morphology.

Unexpectedly, the forage mass production of cv. Mombaça was 1204 kg ha^{-1} higher than those of Massai and Tanzania grasses ($P = 0.03$). This can be explained by the higher WUE of cv. Mombaça, which shows that this cultivar has adaptations to improve its WUE, mainly in situations of lower rainfall, as occurred in the present study in January, February, May, and June, when precipitation averaged 21.4, 15.0, 23.6, and 35.8 mm, respectively. This adaptation is related to the regulation of CO_2 and leaf temperature and decreased water loss provided by changes in stomatal opening (Zandalinas et al., 2018). Interestingly, Costa et al. (2021) reported no difference between three *M. maximum* cultivars (Massai, Tanzania, and Mombaça), although their forage masses were similar to those found in the current study.

Urochloa ruziziensis cv. Kennedy showed lower leaf production than the other *Urochloa* cultivars (P = 0.01) (Table 2). A treatment effect was observed for stem weight (P < 0.01), but not for dead material (P = 0.11), although cv. Llanero showed a higher leaf:stem ratio than the other *Urochloa* grasses (P = 0.03) (Table 2). Within the genus *Megathyrsus*, cv. Mombaça produced twice more stems than the other cultivars (P = 0.03) (Table 2). However, the *Megathyrsus* cultivars did not differ in terms of leaf and dead material weights or leaf:stem ratio (P > 0.05) (Table 2). The leaf is an important structural characteristic of the forage, as it is more nutritious than the other parts of the plant (Tesk et al., 2018). Only *U. ruziziensis* cv. Kennedy had a lower leaf weight. Increased leaf weight implies higher photosynthetic capacity (Vasconcelos et al., 2020). It is possible that *U. ruziziensis* cv. Kennedy had a lower photosynthetic capacity that resulted in lower production of leaves and forage mass than the other *Urochloa* grasses. *Urochloa humidicola* cv. Llanero showed the highest leaf:stem ratio, which influences the quality of the forage and improves grazing efficiency when above 1 (Grev et al., 2020; Mganga et al., 2021). Among the *Megathyrsus* cultivars evaluated, the higher stem weight seen in cv. Mombaça is partially due to the higher forage mass production and the structural characteristics of this cultivar, whose erect growth leads to greater stem weights (Fonseca & Martuscello, 2010).

Table 2
Productivity and morphological traits of forage grasses in the semiarid condition

Variable	Grass[I]						SEM[II]	P-value
	Basilisk	Llanero	MG4	Marandu	Piatã	Kennedy		
Forage mass[III], kg ha^{-1} DM basis	3127[a]	2637[ab]	3230[a]	3335[a]	3136[a]	2061[b]	202.9	<0.01
Leaf, kg ha^{-1}	1210[a]	1102[a]	1344[a]	1570[a]	1373[a]	741[b]	157.9	0.01
Stem, kg ha^{-1}	987[a]	602[c]	1041[a]	944[ab]	1001[a]	512[c]	109.4	<0.01
Dead material, kg ha^{-1}	778	914	844	927	761	465	100.9	0.11
Leaf:stem ratio	1.26[b]	2.03[a]	1.30[b]	1.55[b]	1.37[b]	1.43[b]	0.076	0.03
	Massai	Mombaça	Tanzania					
Forage mass, kg ha^{-1} DM basis	3016[b]	4205[a]	2987[b]				254.2	<0.01
Leaf, kg ha^{-1}	1562	2181	1439				182.5	0.12
Stem, kg ha^{-1}	548[b]	1155[a]	740[b]				95.3	0.03
Dead material, kg ha^{-1}	582	110	225				92.1	0.08
Leaf:stem ratio	1.98	2.21	1.59				0.125	0.15

[I] Basilisk: *Urochloa decumbens* cv. Basilisk; Lanero: *Urochloa humidicola* cv. Llanero; MG4: *Urochloa brizantha* cv. MG4; Marandu: *Urochloa brizantha* cv. Marandu; Piatâ: *Urochloa brizantha* cv. Piatã; Kennedy: *Urochloa ruziziensis* cv. Kennedy; Massai: *Megathyrsus maximum* cv. Massai; Mombaça: *Megathyrsus maximum* cv. Mombaça; Tanzania: *Megathyrsus maximum* cv. Tanzania.
[II] SEM: standard error of the mean.
[III] Forage mass above the stubble.
Means followed by the same letter in the row do not differ by Tukey's test (P < 0.05).

No effect of Urochloa grasses was detected for LAR or phyllochron (P > 0.05) (Table 3). This can be explained by the lower precipitation that occurred in February and March (Figure 1), which possibly contributed for the forage to preserve resources, keeping its leaves green longer without the appearance of new leaves as a mechanism of adaptation to these conditions. Cultivars Marandu and Piatã showed higher LER (P = 0.02). Nevertheless, only U. decumbens cv. Basilisk showed a higher SER among the cultivars of this genus (P = 0.04).

Table 3

Leaf appearance rate, leaf elongation rate, stem elongation rate, phyllochron, leaf lifespan, and tiller density of forage grasses in the semiarid condition

Variable[I]	Grass[II]						SEM[III]	P-value
	Basilisk	Llanero	MG4	Marandu	Piatã	Kennedy		
LAR, leaf tiller^{-1}	0.109	0.093	0.135	0.135	0.144	0.149	0.021	0.44
LER, cm tillers^{-1} day^{-1}	1.39^{b}	1.65^{b}	2.06^{ab}	3.05^{a}	3.21^{a}	2.12^{ab}	0.431	<0.01
SER, stem tillers^{-1} day^{-1}	0.669^{a}	0.451^{b}	0.367^{b}	0.319^{b}	0.275^{b}	0.389^{b}	0.087	0.04
Philochron, day^{-1} leaf $^{-1}$ tiller^{-1}	10.6	13.7	11.9	12.9	10.8	9.75	1.62	0.51
LLS, days	60.5^{b}	62.9^{ab}	59.6^{b}	67.3^{a}	58.4^{b}	58.4^{b}	1.49	<0.01
TPD, tillers m^{-2}	1310^{bc}	2103^{a}	1351^{b}	1156^{bcd}	1022^{cd}	870^{d}	75.9	<0.01
	Massai	Mombaça	Tanzania					
LAR, leaf tiller^{-1}	0.097	0.216	0.196				0.053	0.15
LER, cm tillers^{-1} day^{-1}	2.02^{b}	2.15^{b}	4.00^{a}				0.32	<0.01
SER, stem tillers^{-1} day^{-1}	0.839	1.14	1.02				0.3803	0.81
Philochron, day^{-1} leaf $^{-1}$ tiller^{-1}	14.6	14.2	13.5				3.88	0.96
LLS, days	57.3^{b}	71.4^{a}	65.4^{ab}				2.87	0.02
TPD, tiller m^{-2}	2234^{a}	839b	978^{b}				56.0	<0.01

[I] LAR = leaf appearance rate; LER = leaf elongation rate; SER = stem elongation rate; LLS: leaf lifespan; TPD: tiller density.
[II] Basilisk: *Urochloa decumbens* cv. Basilisk; Lanero: *Urochloa humidicola* cv. Llanero; MG4: *Urochloa brizantha* cv. MG4; Marandu: *Urochloa brizantha* cv. Marandu; Piatâ: *Urochloa brizantha* cv. Piatã; Kennedy: *Urochloa ruziziensis* cv. Kennedy; Massai: *Megathyrsus maximum* cv. Massai; Mombaça: *Megathyrsus maximum* cv. Mombaça; Tanzania: *Megathyrsus maximum* cv. Tanzania.
[III] SEM: standard error of the mean.
Means followed by the same letter in the row do not differ by Tukey's test (P < 0.05).

Cultivar Massai showed the lowest LER among the *Megathyrsus* grasses (P = 0.02) (Table 3). Similarly to the present study, Costa et al. (2021) observed higher LER in cvs. Mombaça and Tanzania compared with Massai. Leaf elongation rate has a positive correlation with forage mass, explaining 90% of its response (Costa et al., 2013). Therefore, a higher LER induces higher forage mass production (Oliveira et al., 2020). Higher LERs can increase tissue turnover, impacting the dead material of the plant. In addition, the higher LER of cv. Mombaça possibly lead to a larger photosynthetic area, resulting in higher forage mass, as supported by the higher SPAD, although the difference in LAI was not statistically significant. The low rainfall in the present study particularly in the middle of the experimental period can be influenced by soil water availability and atmospheric evaporative demand (Artur et al., 2014). Moreover, each species adapted differently, which explains the present results.

In the current study, dead material was not influenced by the *Urochloa* or *Megathyrsus* grasses. *Urochloa humidicola* cv. LInero had a higher tiller density than the other *Urochloa* grasses ($P < 0.01$) (Table 3). In the *Megathyrsus* grasses, the treatments influenced tiller density ($P < 0.05$) (Table 3). *Urochloa brizantha* cv. Marandu showed a longer LLS than the other *Urochloa* grasses ($P < 0.01$). Among the *Megathyrsus* grasses, cv. Mombaça showed the highest LLS ($P = 0.02$; Table 3). Tillers are plant structures that allow regrowth and perenniality (Gastal & Lemaire, 2015). In the current study, *U. humidicola* cv. Llanero showed the highest tiller density, denoting a greater capacity to produce new tillers, which directly affects population density and grazing (Miqueloto et al., 2020). When the grass is cut, the tillers are decapitated, which causes physiological effects, directly interfering with the number of tillers per area. Besides, the growth habits of each cultivar directly influence tiller density, since plants with a caespitose growth habit have a lower population density than those with stoloniferous growth. This lower tiller density in caespitose plants suggests that they reduce the amount of stem, as seen in cultivars Mombaça and Tanzania, to increase their diameter and, therefore, their weight, in a compensatory effect (Santos et al., 2010).

The main differences observed in structural characteristics between the cultivars were caused by climatic factors, which act directly on plant morphology (Iwamoto et al., 2014), due to the phenotypic plasticity the plant develops to ensure its development. The rainfall in January (21.4 mm), February (15.0 mm), and March (59.4 mm) seems to have limited the development of all forages. However, cv. Mombaça apparently had the best WUE, which resulted in higher production compared with the other cultivars of the same genus. Additionally, the different ecophysiological and morphogenetic responses observed in the present study demonstrate that under the environmental action of light, temperature, water, and nutrients, the forage canopy changes its structural characteristics, making adaptations that allow a better utilization of available resources for its development. Beloni et al. (2018) examined *U. brizantha* cvs. *Marandu* and BRS Paiaguás and U. decumbens cv. Basilisk and observed that drought stress reduced leaf expansion and root biomass.

Cultivars Piatã and Kennedy had a shorter leaf lifespan (LLS), due to their taller harvest height. However, this seems to be mediated by the genus and its growth behavior, whereas among the *Megathyrsus* cultivars, cv. Mombaça, harvested at a taller height, had a longer LLS. Ongaratto et al. (2021) evaluated the intensity of grazing on *Urochloa brizantha* cv. Marandu and found that intensity accelerates leaf turnover, decreasing LLS.

In the *Urochloa* and *Megathyrsus* grasses, the treatments did not influence LI or LAI (P > 0.05) (Table 4). Nonetheless, the lower tiller density in *U. ruziziensis* cv. Kennedy can be due to the mechanism of this cultivar to better utilize the resources by the greater length of its tillers.

Table 4

Light interception, leaf area index, SPAD index, relative water content, water use efficiency, water potential and stomatal conductance of forage grasses in the semiarid condition

Item[I]	Grass[II]						SEM[III]	P-value
	Basilisk	Llanero	MG4	Marandu	Piatã	Kennedy		
LI, %	59.6	64.3	65.4	65.7	62.6	62.7	2.95	0.53
LAI	1.64	1.79	1.81	2.08	1.82	1.86	0.099	0.09
SPAD, units	43.8[c]	44.4[bc]	45.8[bc]	50.5[a]	49.1[ab]	44.4[bc]	1.08	<0.01
RWC, %	74.9[b]	82.2[ab]	85.0[a]	86.8[a]	81.1[ab]	77.4[ab]	1.82	0.03
WUE, kg ha^{-1} mm^{-1}	24.6[a]	19.5[ab]	24.2[a]	23.7[a]	22.2[a]	14.5[b]	1.70	<0.01
LWP, MPa	1.20	1.87	1.53	1.20	0.903	1.22	0.1103	0.18
SC, mmol m^{-2} s^{-1}	127[ab]	194[ab]	123[b]	236[a]	193[ab]	190[ab]	26.6	0.02
	Massai	Mombaça	Tanzania					
LI, %	73.9	82.1	78.7				2.86	0.14
LAI	2.53	3.34	2.90				0.280	0.15
SPAD units	38.7[b]	42.0[ab]	44.6[a]				0.99	<0.01
RWC, %	82.7	87.5	88.8				2.44	0.15
WUE, kg ha mm^{-1}	22.6[b]	34.2[a]	24.2[b]				2.275	<0.01
LWP, MPa	1.15	1.24	1.04				0.139	0.79
SC, mmol m^{-2} s^{-1}	124[ab]	162[a]	112[b]				12.9	0.04

[I] Item: LI: light interception; LAI: leaf area index; SPAD = soil plant analyses development; RWC = relative water content; WUE: water use efficiency; LWP = leaf water potential; SC = stomatal conductance.[II] Basilisk: *Urochloa decumbens* cv. Basilisk; Lanero: *Urochloa humidicola* cv. Llanero; MG4: *Urochloa brizantha* cv. MG4; Marandu: *Urochloa brizantha* cv. Marandu; Piatâ: *Urochloa brizantha* cv. Piatã; Kennedy: *Urochloa ruziziensis* cv. Kennedy; Massai: *Megathyrsus maximum* cv. Massai; Mombaça: *Megathyrsus maximum* cv. Mombaça; Tanzania: *Megathyrsus maximum* cv. Tanzania.
[III] SEM: standard error of the mean.
Means followed by the same letter in the row do not differ by Tukey's test (P < 0.05).

Urochloa brizantha cv. Marandu and Piatã showed a higher SPAD index than the other *Urochloa* cultivars (P < 0.01). *Megathyrsus maximum* cv. Tanzania had a 6.6% higher SPAD index than *M. maximum* cvs. Massai and Mombaça (P < 0.01; Table 4). This indicates a reduction of leaf area in forages with a low SPAD index, which can compromise plant growth, to avoid water losses (Cheruiyot et al., 2018). In the present study, *U. brizantha* cvs. Marandu and Piatã and *M. maximum* cv. Tanzania could seemingly better modulate this water loss under drought stress. The SPAD index is used as an indicator of chlorophyll concentration, and is closely related to the CP content of the forage (Vidigal et al., 2018). In the present study, cvs. Marandu and Piatã had the highest chlorophyll indices; interestingly, the same occurred for the CP content of these two cultivars. Moreover, photosynthesis is limited by the chlorophyll concentration (Dinh et al., 2017), and a lower chlorophyll concentration would partially limit growth. Szulc et al. (2021) observed that SPAD can be a predictor of DM production in maize (*Zea mays* L.).

Relative water content differed between the *Urochloa* grasses (P = 0.03), but not between the *M. maximum* cultivars (P = 0.15). A higher RWC indicates lower cell damage and higher water-holding capacity (Malinowski & Belesky, 2000), representing a mechanism to avoid water losses, mainly in semiarid conditions. Additionally, a low water soil content causes the stomata to close, reducing CO_2 assimilation and leaf transpiration and expansion (Artur et al., 2014).

Urochloa ruziziensis cv. Kennedy had 36.4% lower WUE than the other *Urochloa* treatments (P < 0.01) (Table 4). In the *Megathyrsus* grasses, the treatments influenced WUE (P < 0.05) (Table 4). For the *Urochloa* cultivars and *M. maximum,* the treatments did not affect leaf water potential (P > 0.05) (Table 4). In addition, a treatment effect was detected for stomatal conductance (P < 0.05) in the *Urochloa* grasses and *M. maximum* cultivars (Table 4). Stomatal conductance is influenced by many factors such as light, vapor pressure deficit, boundary layer, and [CO_2] (Habermann et al., 2019). Marandu and Mombaça had higher stomatal conductance than the other treatments, when compared within the same genus. Higher stomatal conductance induces lower net photosynthetic rate and WUE (Santos et al., 2017). Contrary to the aforementioned study, in the current experiment, the treatments with higher stomatal conductance also showed higher WUE.

Water use efficiency by different cultivars is important, as it demonstrates the plant's potential to transform the amount of water it absorbed into DM (Beloni et al., 2018). Therefore, the main difference between the different cultivars in this regard may be attributed to the intrinsic characteristics of each plant, since an adequately nourished plant expresses its full productive potential and becomes more efficient in absorbing and using water available in the soil (Hatfield & Dold, 2019). Knowledge about WUE in tropical forage grasses is essential, as it indicates the plant's tolerance to low rainfall conditions (Perazzo et al., 2013). Another explanation for the higher WUE and higher forage mass observed in the current study would be a greater root weight, which allowed greater extraction of water from the deeper layer of the soil, as shown in the study of Beloni et al. (2018).

The *Urochloa* grasses influenced the CP, NDF, ADF, TDN, and total soluble sugars (TSS) contents and DMD (P < 0.05) (Table 5). Among the *Megathyrsus* grasses, cv. Massai showed higher NDF (35.5 g kg^{-1} DM; P < 0.01) and lower ash contents (P < 0.01). The *Megathyrsus* grasses did not influence the CP, ADF, or TDN contents or DMD (P > 0.05) (Table 5), but cvs. Massai and Mombaça exhibited higher TSS (40.4%; Table 5). The grasses showed protein levels above 140 g kg^{-1} DM, which is due to the double application of nitrogen fertilizer, which favored high levels of CP, as well as the harvesting that was performed according to the recommended management height. The plants did not reach a 95% light interception value; therefore, they were in the vegetative stage. Young plants have a larger number of leaves, as evidenced by the leaf:stem ratio, which affects the protein content (Pontes et al., 2017), as observed mainly in cv. Marandu.

Table 5
Nutritional value and dry matter digestibility of forage grasses in the semiarid condition

Item[I], g kg^{-1} DM	Grass[II]						SEM[III]	P-value
	Basilisk	Llanero	MG4	Marandu	Piatã	Kennedy		
CP	149^{c}	163^{abc}	158^{bc}	176^{a}	165^{abc}	170^{ab}	3.9	<0.01
NDF	551^{ab}	562^{a}	535^{bc}	529^{bc}	555^{ab}	513^{c}	6.1	<0.01
ADF	269^{a}	271^{a}	263^{a}	256^{ab}	260^{ab}	244^{b}	3.9	<0.01
ash	82.0	87.1	83.2	82.7	80.9	85.8	1.66	0.06
TDN	593^{b}	591^{b}	596^{b}	600^{ab}	598^{ab}	607^{a}	3.2	<0.01
TSS, mg g^{-1}	27.4^{b}	34.1^{ab}	30.6^{b}	28.7^{b}	39.7a	35.9^{ab}	1.50	0.01
DMD	679^{b}	677^{b}	683^{b}	689^{ab}	686^{ab}	699^{a}	3.1	<0.01
	Massai	Mombaça	Tanzania					
CP	161	166	178				5.4	0.07
NDF	579^{a}	559^{b}	528^{c}				5.3	<0.01
ADF	299	304	290				9.7	0.57
ash	92.5^{b}	100^{ab}	104^{a}				2.5	<0.01
TDN	576	573	581				7.7	0.57
TSS, mg g^{-1}	28.7^{a}	28.3^{a}	20.3^{b}				2.73	<0.01
DMD	655	651	662				7.5	0.58

[I] CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; TDN: total digestible nutrients; TSS = total soluble sugars; DMD: dry matter digestibility.
[II] Basilisk: *Urochloa decumbens* cv. Basilisk; Lanero: *Urochloa humidicola* cv. Llanero; MG4: *Urochloa brizantha* cv. MG4; Marandu: *Urochloa brizantha* cv. Marandu; Piatâ: *Urochloa brizantha* cv. Piatã; Kennedy: *Urochloa ruziziensis* cv. Kennedy; Massai: *Megathyrsus maximum* cv. Massai; Mombaça: *Megathyrsus maximum* cv. Mombaça; Tanzania: *Megathyrsus maximum* cv. Tanzania.
[III] SEM: standard error of the mean.
Means followed by the same letter in the row do not differ by Tukey's test (P < 0.05).

The NDF and ADF levels reinforce the understanding of the function of structural carbohydrates in grasses, which have lower digestibility. The *Urochloa* grasses with higher NDF and ADF content also exhibited low TDN and DMD. More importantly, the observation of the ADF content is indicative of the digestibility and the energy value of the feed, where lower ADF values imply a greater energy value of the forage (Magalhães et al., 2015). This can be explained by the higher digestibility of non-fibrous carbohydrates. The lower stem production of cv. Kennedy explains the higher TDN and DMD shown by this cultivar. This can be attributed to the spatial structure of cv. Kennedy, which has lower tiller density and SER. Among the *Megathyrsus* cultivars, the treatments only affected NDF and ash, and because of this, no difference was observed in the TDN or DMD of these cultivars.

Conclusion

Cultivars Marandu, Piatã, and Massai had better productive responses in the edaphoclimatic conditions of this study. However, further research must be conducted evaluating the adaptation of these forages under semiarid conditions. Considering the settings of this study, the grasses *Urochloa brizantha* cvs. MG4, Marandu, and Piatã, as well as *Megathyrsus maximum* cvs. Massai and Mombaça, can be used in the semiarid condition.

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