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Morphogenic and structural characteristics of *Panicum* cultivars during the establishment period in the Brazilian Northeast

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ABSTRACT. This study aimed to evaluate the morphogenic and structural characteristics of six *Panicum maximum* cultivars during the establishment period. A completely randomized block design with four replicates and six treatments (Tamani, Mombaça, Massai, Tanzania, Aruana and Zuri cultivars) was used. Morphogenic (leaf appearance rate, leaf elongation rate e stem elongation rate), structural (final leaf length, tiller population density e number of leaves per tiller) and productive (forage mass, leaf blade mass, stem mass, senescent material mass and leaf:stem ratio) characteristics were evaluated. There was no difference ($p > 0.05$) between the cultivars in terms of the number of live leaves per tiller (2.95 leaves/tiller). Mombaça cultivar had ($p < 0.05$) higher canopy height (50.64 cm) compared with other cultivars. The highest ($p < 0.05$) tiller population density was observed in Tamani (235.90 tillers m^{-2}) and Massai (201.60 tillers m^{-2}) cultivars. Leaf lifespan (54.18 days), phyllochron (17.40 days/leaf) and leaf senescence rate (0.87 cm tiller day^{-1}) were not different ($p > 0.05$) between cultivars. However, leaf appearance rate was higher ($p < 0.05$) in Tanzania (0.07 leaves tiller day^{-1}) than in Aruana cultivar (0.05 leaves tiller day^{-1}). Leaf blade mass was higher ($p < 0.05$) in Mombaça cultivar (1518.31 kg DM ha^{-1}), whereas Massai showed higher ($p < 0.05$) leaf:stem ratio (9.25). *Panicum* cultivars Tamani, Tanzania and Massai establishment after 75 days, while the other cultivars establish at 105 days of sowing in the Brazilian Northeast.

Keywords: implantation; morphogenesis; *Panicum maximum*.

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Introduction

Pasture establishment is one of the most critical stages of livestock production in the tropics. Perennial cultures should be used for maintaining pasture vigor, satisfactory productivity and forage quality levels for sustainable livestock production (Gomide & Gomide, 2000). However, the choice of forage species is not a simple process since pasture establishment and longevity depend on plants, climate and soil interactions (Bauer, Pacheco, Chichorro, Vasconcelos, & Pereira, 2011).

Panicum maximum is one of the most used forage species in animal production systems in Brazil due to its adaptation to tropical and subtropical climates and high productivity (Gomes, Lempp, Jank, Carpejani, & Morais, 2012). Moreover, this species possesses several desirable traits, including abundant leaf production (Emerenciano Neto et al., 2017), nutritional value and acceptability by animals (Euclides et al., 2018). Despite being considered adaptable to different edaphoclimatic characteristics (Mochel Filho et al., 2016; Gurgel et al., 2017; Euclides et al., 2018; Pereira, Emerenciano Neto, Difante, Assis, & Lima, 2019), some factors may limit *Panicum maximum* development during the establishment period.

It is essential to understand the morphophysiological mechanisms and their interaction with the environment during pasture establishment (Garcez Neto et al., 2002). Morphogenesis reflects the dynamics of appearance and expansion of plant components in time and space (Luna et al., 2014). The morphological responses of forage cultivars to the environment is fundamental to identify plant adaptation strategies and choose cultivars with vigorous establishment. The aim was to evaluate the morphogenic and structural characteristics of six *Panicum maximum* cultivars during the establishment period in the Brazilian Northeast.

Material and methods

The experiment was performed at the Forage Study Center (GEFOR), belonging to the Specialized Unit in Agricultural Sciences - Federal University of Rio Grande do Norte - UFRN, in Macaíba, RN (5° 53’ 35.12” S and 35° 21’ 47.03” W), from April 9 to July 29, 2016.

According to the Thornthwaite's classification (Thorthwaite, 1948), the climate is dry sub-humid, with a rainy season from May to August. The average monthly rainfall and minimum, average and maximum temperatures were obtained from the INMET - National Institute of Meteorology database. During the experimental period, an average temperature of 27.1 C (30.5 and 23.5°C, maximum and minimum temperature, respectively) was observed and a total precipitation of 394 mm (Figure 1).

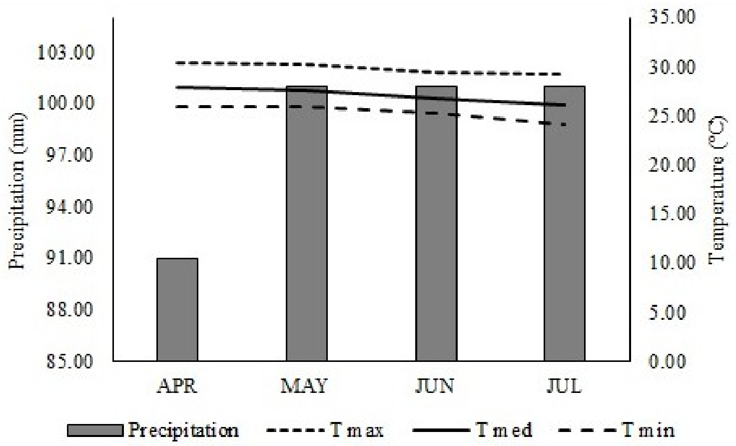

Figure 1. Precipitation (mm) and minimum (Tmin), average (Tmed) and maximum (Tmax) temperatures (°C) from April to July 2016.

The soil of the experimental area is classified as Quartzarenic Neosol. At the beginning of the experiment, chemical analyses of the soil were performed at 0 - 20 and 20 - 40 cm depth layers (Table 1). A total of 105 kg ha^{-1} of single superphosphate and 164 kg ha^{-1} of potassium chloride were applied at sowing, in addition to 500 kg ha^{-1} of limestone to raise base saturation to 80%. Nitrogen in the form of ammonium sulfate was applied 42 days after sowing at a rate of 50 kg ha^{-1}, in single application when soil moisture was favorable.

Table 1. Soil chemical characteristics of the experimental area at 0 to 20 and 20 to 40 cm depths.

Depths (cm)	P	K	Na	pH	Ca	Mg	Al	H+Al	CEC	BS (%)	Granulometry (%)		
	--mg dm^{-3}--				cmol$_c$/dm^3						Sandy	Silt	Clay
0-20	18.0	63.0	20.0	6.6	3.1	0.2	0.0	1.2	4.4	72.7	84.6	4.0	11.4
20-40	8.0	49.0	13.0	5.6	0.9	0.1	0.0	1.1	2.2	50.0	85.2	2.0	12.8

CEC: cation exchange capacity; BS: base saturation.

A completely randomized block design with six treatments and four replicates was used. Six *Panicum maximum* cultivars were evaluated: Tamani, Mombaça, Massai, Tanzania, Aruana and Zuri. The experimental area (750 m²) consisted of 24 plots divided into four blocks. Each block consisted of six plots with 1.0 m spacing between plots and 2.0 m between blocks. The plots had dimensions of 2.0 m x 2.0 m = 4.0 m² with 1.3 m² of usable area and 0.70 m² from each side as the border. Broadcasting sowing was performed on April 9, 2016. From 50 to 70 pure seeds per m^2 were used. Sowing was performed manually after soil preparation. The sowing depth was one to three cm. A hand compactor was used to improve soil-seed contact.

Pasture canopy height was measured every 15 days at ten representative points per plot using a millimeter ruler. The canopy height at each point corresponded to the average height of the curvature of upper leaves around the ruler (Luna et al., 2016).

Morphogenic characteristics were assessed in three tillers per experimental unit. The total length of expanded and expanding leaf blades, the senescent area in expanded leaves and the pseudo stem (stem + sheath) length were measured in each tiller, as well as the distance from the ligule of the last expanded leaf to the base of the tiller.

Leaf appearance rate was calculated by dividing the total number of leaves that emerged in a tiller by the regrowth period (LAR, leaves tiller day^{-1}); phyllochron was estimated as the inverse of leaf appearance rate (Phyll, days leaves tiller^{-1}); leaf elongation rate was calculated by dividing the accumulated leaf length in the tiller by the evaluation period (LER, cm tiller day^{-1}); leaf stretching rate was obtained by dividing the accumulated pseudostem (stem + sheath) length in the tiller by the evaluation period (SER, cm tillers day^{-1}); the final leaf length was calculated as the product of leaf expansion rate by the leaf stretching duration (FLL, cm/tiller); the number of live leaves per tiller was obtained by considering the maximum number of live leaves during the evaluation period (NLL, leaves/tiller); leaf lifespan was estimated from the period from leaf emergence until the first sign of senescence, calculated as the product of NLL by Phyll (LL, days); leaf senescence rate was calculated by dividing the accumulated leaf senescence length in the tiller by the evaluation period (LSR, cm tiller day^{-1}). These variables were calculated as described by Montagener et al. (2012a).

Tiller population density (TPD) was estimated by placing two frames of 0.25m^2 at each experimental unit for counting all tillers contained in each frame. Data were collected biweekly and transformed into tillers m^{-2} (Luna et al., 2016).

Forage mass (FM) was evaluated 105 days after sowing by cutting forage samples 15 cm above ground level and weighing the sampled material contained in a 1.0 m^2 square. Then, a sub-sample was taken and weighed again to determine the green mass; after, the sample was oven-dried at 55°C for 72 hours to determine the dry matter content (Luna et al., 2016).

Another sub-sample was used to evaluate the morphological composition (leaf blade, stem + sheath and senescent material). These components were oven-dried, as previously described, for estimation of the leaf blade, stem and senescent material mass and leaf:stem ratio. Data on forage mass and morphological components were converted to (kg DM ha^{-1}).

Data were subjected to analysis of variance and, if significant, to the F-test ($\alpha = 0.05$). The means and interactions for cultivars were compared by the Tukey's test. Regression analysis was used for evaluation periods only for those characteristics assessed every 15 days, using the statistical software Sisvar, version 4.6 (Ferreira, 2014).

Results and discussion

There was no interaction between cultivar and evaluation period for TPD, pasture canopy height, number of leaves per tiller and number of tillers per plant. There was no difference between the cultivars in terms of the number of live leaves per tiller (Table 2) since it is a genetically determined characteristic; therefore, there are few variations among cultivars of the same species, although genus differences are expected (Luna et al., 2014). The number of live leaves per tiller in Tanzania and Mombaça cultivars was lower than the value of 3.5 reported by Gomide e Gomide (2000). However, NLL was higher in the Massai cultivar compared to the value (2.3) reported by Pereira et al. (2019). These studies were conducted under different edaphoclimatic conditions; thus, despite being a genetically determined trait, it was influenced by environmental conditions, because in the Pereira et al. (2019) the accumulated precipitation was 56.80 mm, without precipitation in the months of August, October and December, while in this work the accumulated precipitation was 394 mm with rainfall occurring in all months of the work. Canopy height was highest in Mombaça because it is the tallest variety of *Panicum maximum* (Silveira et al., 2010; Luna et al., 2016).

Table 2. Canopy height, tiller population density (TPD), number of tillers per plant (NTP), number of leaves per tiller (NLL) in *Panicum maximum* cultivars during the establishment period.

Characteristics	Tamani	Mombaça	Massai	Tanzania	Aruana	Zuri	P value	SEM
Canopy height (cm)	30.44^{cd}	50.64^{a}	27.01^{d}	36.28^{b}	30.75^{cd}	33.11^{bc}	0.001	1.20
TPD (tiller m^{-2})	235.90^{a}	78.95^{c}	201.60^{a}	136.00^{b}	109.90^{c}	97.20^{c}	0.001	18.28
NTP	8.35^{b}	4.95^{b}	18.35^{a}	8.20^{b}	4.70^{b}	4.25^{b}	0.001	1.02
NLL	3.05	2.90	3.25	3.45	2.20	2.85	0.199	0.18

Means followed by different letters in the row differ by Tukey's test at a confidence level of 5% ($p > 0.05$). SEM: mean standard error.

Tamani and Massai cultivars showed higher tiller population densities compared with Zuri, Mombaça and Aruana cultivars (Table 2). This result can be explained by the compensatory tiller size/population density mechanism (Sbrissia & Silva, 2008) where taller plants have large tillers, but in smaller amounts. The Massai cultivar showed the highest number of tillers per plant due to its high tillering capacity (Martuscello et al., 2015). When assessing the tillering capacity of tropical forage cultivars, Luna et al. (2016) reported a tiller population 62% higher in Massai compared with the Mombaça cultivar. Another advantage of Massai cultivar is that numerous tillers are essential for pasture persistence due to their better efficiency in using resources such as water, nutrients and light (Lopes, Cândido, Pompeu, Silva, & Bezerra, 2011.), which promotes a fast recovery after a period of water shortage (Gurgel et al., 2017).

Tiller population density did not change throughout the experimental period (Table 3), confirming that tiller population stabilized after the beginning of the evaluation. This result may be associated with fertilization, which provided a similarity condition in nutrient extraction by cultivars since the beginning of the experimental period. The number of tillers m^{-2} was lower than that reported by Luna et al. (2016) for Massai (1019.52 tillers m^{-2}) and Mombaça (397.32 tillers m^{-2}) cultivars during the establishment period (150 days) in the Brazilian Northeast (5° 89' 25.78" south and 35° 36' 37.05" west). This disparity between results is associated with the cut performed at 65 days after sowing, which allowed a rapid change in light quantity and quality reaching the base of the plant, stimulating tillering (Difante et al., 2011).

Table 3. Evolution of tiller population density (TPD), canopy height, number of tillers per plant (NTP), number of leaves per tiller (NLT) of *Panicum maximum* cultivars during the establishment period.

Characteristics	Days after sowing					P value		R^2
	45	60	75	90	105	Linear	Quadratic	
TPD (tiller m^{-2})	164.5	145.54	136.75	136.41	133.08	0.152	0.097	-
Canopy height (cm)	13.34	31.73	36.4	43.99	48.1	0.033	0.198	86.08
NTP	7.3	7.1	7.2	7.6	8.97	0.252	0.062	-
NLT	3.07	3.2	3.24	3.18	2.87	0.209	0.003	60.3

SEM: mean standard error. TPD = 143.25; Canopy height = 0.4644x - 1.0430; NTP = 7.63; NLT = $0.0002x^2 + 0.0308x + 2.1199$.

Canopy height data fitted to a linear model as a function of the evaluation period, with estimated increases of 0.46 cm per day (Table 3). The cultivars' behavior is consistent with the establishment period, which shows an increase in canopy height in response to the stage of full growth, regardless of cultivar. Cutting and grazing heights are widely used as a reliable management criterion for controlling and monitoring the regrowth process (Euclides et al., 2018); however, the mean heights for the studied cultivars were below than the recommended for grazing or cutting *Panicum maximum* species (Carnevalli et al., 2006; Barbosa et al., 2007; Emerenciano Neto et al., 2017).

The number of leaves per tiller showed a quadratic response. It is estimated that the number of leaves per tiller would reach its maximum of 3.25 on day 73. Since it is a genetically determined characteristic, the number of leaves per tiller increases until it reaches its limit (73 days); therefore, for each new leaf that emerges, another goes into senescence (Pilbeam, 1992; Candido, Gomide, Alexandrino, Gomide, & Pereira, 2005). Leaf lifespan (54.18 ± 5.06 days), phyllochron (17.40 ± 1.34 days/leaf) and leaf senescence rate (0.87 ± 0.15 cm/tiller.day^{-1}) were not significantly different among *Panicum maximum* cultivars during the establishment period. These characteristics are mainly regulated by environmental conditions such as light, water availability, temperature and soil fertility (Montagner et al., 2012b; Martuscello et al., 2015).

Leaf appearance rate (LAR) differed between Tanzania and Aruana, with the highest and lowest values for those cultivars, respectively, while Tamani, Mombaça, Massai and Zuri cultivars obtained intermediate values (Table 4). The Aruana cultivar entered the reproductive stage during the establishment period; leaf appearance stops after the appearance of inflorescence (Silveira et al., 2010). Aruana cultivar also showed the lowest leaf elongation rate (LER) due to its reproductive stage.

The reproductive stage of Aruana grass led to the highest stem stretching rate (SER) among cultivars, which stimulates stem stretching to produce the inflorescence. Hazard, Barker e Easton (2001), when analyzing factors such as environment, soil and plant plasticity, reported that the environment is the factor that most interferes with morphogenic characteristics. The environment was the main factor to cause early flowering on Aruana cultivar. According to Luna et al. (2014), rapid flowering after the first rains is common for some forage grasses in the Brazilian Northeast. The highest FLL was observed in the Mombaça cultivar due to its tall size.

Table 4. Means of morphogenic and structural characteristics in *Panicum maximum* cultivars during the establishment period.

Characteristics	Tamani	Mombaça	Massai	Tanzania	Aruana	Zuri	P value	SEM
LAR (leaves tiller^{-1} day^{-1})	0.06^{ab}	0.06^{ab}	0.06^{ab}	0.07^{a}	0.05^{b}	0.06^{ab}	0.029	0.01
LER (cm tiller^{-1} day^{-1})	1.73^{a}	2.26^{a}	1.46^{ab}	2.15^{a}	0.61^{b}	1.21^{ab}	0.001	0.23
SER (cm/tiller.day^{-1})	0.10^{ab}	0.15^{ab}	0.08^{b}	0.16^{ab}	0.25^{a}	0.08^{b}	0.024	0.04
FLL (cm tiller^{-1})	22.84^{ab}	28.56^{a}	19.54^{ab}	21.69^{ab}	8.09^{c}	16.42^{bc}	0.001	2.06

Leaf appearance rate (LAR), leaf stretching rate (LER), stem stretching rate (SER), final leaf length (FLL). Means followed by different letters in the row differ by Tukey's test at a confidence level of 5% (p > 0.05). SEM: mean standard error.

There was no difference between cultivars for forage mass (FM). Even though variations were observed in the morphogenic traits and especially in TPD, which has a high correlation with forage mass at harvesting (Santos et al., 2012), there were no changes in FM. Cultivars with the highest tiller population densities and lowest canopy heights (Table 2) had smaller and lighter tillers, which promotes a compensatory effect on FM. There was a similarity between cultivars for stem mass (SM), senescent material mass (SeM) and undesirable plant mass (UnM) during the establishment period (Table 5). These cultivars were not high enough to intercept 95% of light, possibly not triggering stem accumulation and senescence losses due to competition for light (Carnevalli et al., 2006; Barbosa et al., 2007).

Table 5. Means of forage mass (FM), leaf blade mass (LBM), stem mass (SM), senescent material mass (SeM), undesirable plant mass (UnM) and leaf:stem ratio of *Panicum maximum* cultivars during the establishment period.

Characteristics	Tamani	Mombaça	Massai	Tanzania	Aruana	Zuri	P value	SEM
FM (kg DM ha^{-1})	4329.97	3709.18	2739.46	3115.52	2678.15	2414.95	0.199	559.37
LBM (kg DM ha^{-1})	1031.44^{ab}	1518.31^{a}	1274.03^{ab}	714.33^{ab}	255.88^{b}	581.98^{b}	0.017	234.61
SM (kg DM ha^{-1})	190.08	611.48	141.06	144.47	133.35	167.87	0.062	113.84
SeM (kg DM ha^{-1})	539.93	614.63	256.71	357.61	385.65	332.52	0.287	115.22
UnM (kg DM ha^{-1})	1751.02	616.00	625.29	1376.30	1445.27	934.36	0.341	422.37
L:S ratio	4.87^{ab}	2.92^{b}	9.25^{a}	2.75^{b}	1.95^{b}	3.59^{b}	0.003	1.08

Means followed by different letters in the row differ by Tukey's test at a confidence level of 5% (p > 0.05). SEM: mean standard error.

The Mombaça cultivar showed the highest leaf blade mass (LBM) compared with the other cultivars. This characteristic was influenced by the LER because it is the morphogenic variable that correlates most with LBM (Costa et al., 2014). Furthermore, the Mombaça cultivar has high leaf yield and the LBM can reach up to 66% of FM during the establishment period (Gomide, Gomide, & Alexandrino, 2003). The highest leaf:stem ratio was observed in the Massai cultivar, followed by Tamani, due to the lower SM in these cultivars, since this ratio is the product of leaf blade mass by stem mass.

Conclusion

Panicum cultivars Tamani, Tanzania and Massai establishment after 75 days, while the other cultivars establish at 105 days of sowing in the Brazilian Northeast. These cultivars showed optimum morphogenic and structural characteristics during the establishment period and can be considered alternative forage sources for the Brazilian Northeast; however, studies evaluating these plants after the establishment period are essential to assess their persistence.

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