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Morphogenetic and structural traits of tillers and herbage accumulation of Tanganyika grass under shading levels

Características morfogênicas e estruturais de perfilhos e acúmulo de forragem do capim-tanganica sob níveis de sombreamento

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ABSTRACT

This study aimed to evaluate the effect of tree shading levels on tillers' morphogenetic and structural traits, besides the herbage accumulation of Tanganyika grass (*Megathyrsus maximus* Jacq. cv. Tanganyika). For that, an experiment was carried out from December 2010 to March 2012, under a completely randomized design, with four treatments (shading levels) and five repetitions. Phyllochron (PHY), leaf and stem elongation rates (LER and SER, respectively), number of leaves per tiller (NLT), leaf blade length (LBL), stem length (ST), tiller population density (TPD), leaf (LGR) and stem growth rates (SGR), senescence rate (SR) and herbage accumulation rate (HAR) were assessed. Excepted by the LER and NLT, the shading levels influenced the other morphogenetic variables ($P<0.05$), positively or negatively. Except in the spring, the TPD linearly increased because of the shading levels ($P<0.05$). At tiller level, except in the spring, the LBL linearly increased with the shading levels ($P<0.05$). In general, the SL linearly decreased with the shading levels. Regarding the growth rates, summer II and spring provided greater values, and the lowest one occurred in autumn ($P<0.05$). The adjustments of both morphogenetic and structural traits ensured the Tanganyika grass a great adaptation to the shaded environment.

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Keywords: forage production, *Megathyrsus maximus*, morphogenesis, shaded environments

RESUMO

Objetivou-se avaliar o efeito do sombreamento arbóreo sobre as características morfogênicas e estruturais dos perfilhos e acúmulo de forragem do capim-Tanganica (*Megathyrsus maximus* Jacq. cv. Tanganica). Para tanto, um experimento foi conduzido, de dezembro de 2010 a março de 2012, sob delineamento inteiramente casualizado com quatro tratamentos (níveis de sombreamento) e cinco repetições. Foram avaliados: filocrono (FIL), taxas de alongamento de lâminas foliares (TAlLF) e de colmos (TAlC), número de folhas vivas por perfilho (NFVP), comprimento de lâminas foliares (CLF), comprimento de colmo (CC), densidade populacional de perfilhos (DPP), taxas de crescimento de lâminas foliares (TCLF) e de colmos (TCC), taxa de senescência (TS) e taxa de acúmulo de forragem (TAF). Exceto para TAlLF e NFVP, todas as demais varáveis morfogênicas foram influenciadas (P<0.05), de maneira positiva ou negativa pelos níveis de sombreamento. Exceto na primavera, a DPP aumentou linearmente sob maiores níveis de sombreamento (P<0.05). Em nível de perfilho, exceto na primavera, o CLF aumentou linearmente com o aumento do nível de sombreamento (P<0.05). Além disso, de maneira geral, o CC reduziu de maneira linear com o aumento do nível de sombreamento. Quanto às taxas de crescimento, o verão II e a primavera proporcionaram maiores valores, e as menores taxas foram registradas no outono (P<0.05). Os ajustes das características morfogênicas e estruturais garantiram ao capim-Tanganica ótima adaptação ao ambiente sombreado.

Palavras-chave: ambientes sombreados, *Megathyrsus maximus*, morfogênese, produção de forragem.

INTRODUCTION

Brazil has a herd of cattle estimated at 172.2 million animals and 149,670,217 hectares of grasslands (ABIEC, 2020), which brings social pressure for more sustainable livestock on integrated systems like the silvopastoral ones (LIMA et al., 2018; PACIULLO et al., 2021). The success of these systems depends on some ecological and management factors, besides the choice of forage species (LIMA et al., 2020).

In silvopastoral systems, the light radiation is lower under the treetops, and this influences the determinant morphogenetic traits of productivity and nutritional value (LIMA et al., 2018; PACIULLO et al., 2021). Shading tolerance will depend on the species' phenotypic plasticity related to changes in morphogenetic and structural traits to increase the radiation-use efficiency (GASTAL & LEMAIRE, 2015; PACIULLO et al., 2017).

Cultivars from *Megathyrsus maximus* Jacq. are good options for silvopastoral systems, because they have large genetic variability that allows selecting shading-tolerant genotypes (VICTOR et al., 2015). Tanganyika cultivar has a short size, thin stems and narrower leaves than other genotypes from the species (ALCÂNTARA & BUFARAH, 1980).

These morphological traits suggest a greater nutritional value and shading tolerance compared to other cultivars like Tanzania and Mombaça (CARVALHO et al., 2021b).

Defoliation management also affects the morphogenetic and structural traits of tillers (PEREIRA et al., 2017). Thereby, the light interception of 95%, which determines the critical leaf area index (LAI), has been adopting as grazing management criterion. In this management, photosynthetic rates are optimized and the net herbage accumulation is near to the maximum, with a great proportion of leaves and lower one of dead material (MARTINS et al., 2021). Cultivars of *Megathyrsus maximus* Jacq. have been managed successfully in this way (SANTIAGO-HERNADÉZ et al., 2016; PACIULLO et al., 2017; CARNEVALLI et al., 2021).

However, the adjustments of morphogenetic and structural traits caused by shading levels tend to be different according to species and ecological factors (LEMAIRE et al., 2011). Furthermore, there is low information about the use of critical LAI as a management criterion of swards under tree shadings. Based on this context, this study aimed to evaluate the effects of tree shading levels on morphogenetic and structural traits of tillers, besides the herbage accumulation of *Megathyrsus maximus* Jacq. cv. Tanganyika.

MATERIAL AND METHODS

The experiment was carried out at the Experimental Field of Animal Nutrition and Grassland Department, Animal Science Institute, from the Federal Rural University of Rio de Janeiro (DNAP/IZ – UFRRJ), municipality of Seropédica – RJ, 22°45’ S, 43°41’ W, at 33 meters altitude. The region’s climate is classified as *Aw* according to the Köppen climate classification (ALVARES et al., 2013), with a dry season lasting from April to September, and a rainy season lasting from October to March. Climate data during the experimental period (Figure 1) were obtained from INMET (2013).

Tanganyika grass was cropped in 20 plots (experimental units) sized 8.0 m^2 each, on March 2010. Maintenance fertilizations were made with 200 kg ha^{-1} $year^{-1}$ N and K_2O using commercial urea and potassium chloride as sources. Fertilizers were equally splitted into five applications: three in spring and summer, and the remaining two in autumn and winter. Phosphate fertilizer was also applied on 11/23/2010, with 80 kg ha^{-1} P_2O_5 using simple superphosphate.

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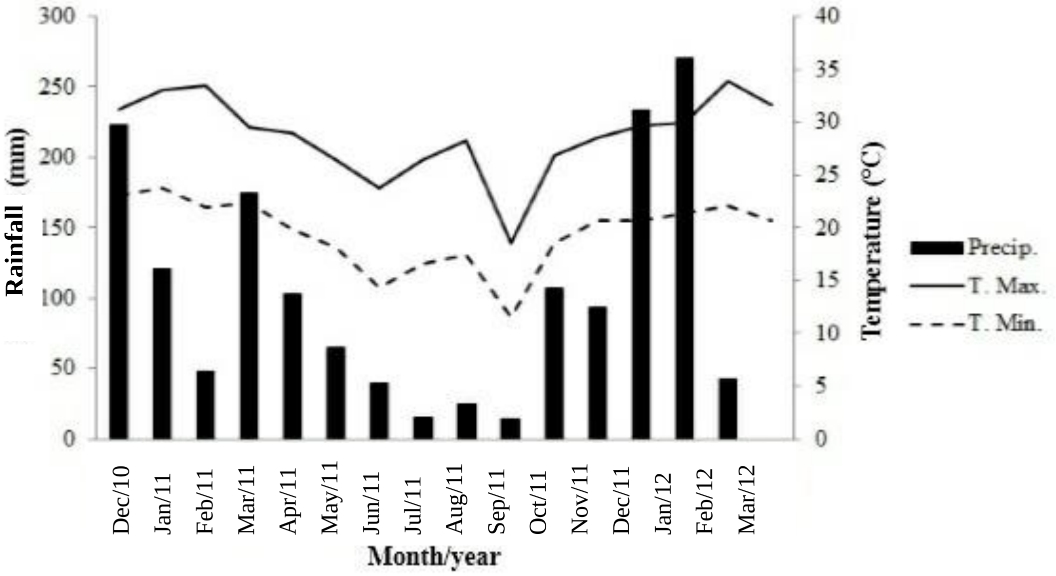

Figure 1. Maximum (T. Max.) and minimum (T. Min.) temperature, besides the average monthly rainfall (Rainfall) recorded during the experimental period. Source: Seropédica-Agricultural Ecology-A60 Station, Seropédica- RJ.

The experiment was carried out in the seasons of summer I (12/27/2010 to 03/20/2011), autumn (03/21/2011 to 06/21/2011), spring (09/22/2011 to 12/20/2011) and summer II (12/21/2011 to 03/01/2020). Historically, these seasons have important climatic differences related to average rainfall and temperature (ALCÂNTARA & SCHUELER, 2015). Treatments consisted of the average shading levels evaluated under treetops of *Clitoria fairchildiana*, commonly known as “sombreiro” or “cow’s shadow”. The trees already existed in 0.5 hectares of a pasture formed 15 years ago, with 20 trees randomly dispersed that allowed stratified shading intensities in the experimental area. Below the trees, areas that showed homogeneous shading levels were selected, sites in which the experimental units (plots) were allocated.

Shading levels were weekly evaluated under the trees at 9:00 a.m., 12:00 p.m. and 3:00 p.m., using the canopy analyzer AccuPAR Linear PAR/LAI ceptometer, Model PAR LP – 80 in 12 points below the trees and above the forage canopy of each plot, and described as averages of the three seasons (Table 1). These shading levels were classified as slight (SS), mild (MS) and heavy (HS). Moreover, Tanganyika grass was also evaluated under full sun (FS) condition as the control treatment (without shadow). The experiment was conducted in a completely randomized design with five repetitions. Photosynthetic active radiation (PAR) above the treetops in the summer I, autumn, spring and summer II were 1,564, 1,456, 1,307 and 1,776-µmol m^{-2} s^{-1}, respectively. The PAR above of treetops was considered the radiation evaluated in the plots under FS.

Table 1. Average levels of *Clitoria fairchildiana* shading on Tanganyika grass canopy in the seasons of summer I, spring and summer II.

Season	Shading levels			
	FS (%)	SS (%)	MS (%)	HS (%)
Summer I	0	26	46	54
Autumn	0	40	67	74
Spring	0	27	54	59
Summer II	0	31	47	56

FS: full sun; SS: slight shading; MS: mild shading; HS: heavy shading. Summer I: 2010/2011, spring 2011, summer II, 2011/2012.

The technique of marked tillers (CARRÈRE et al., 1997) was applied to evaluate morphogenetic and structural traits, besides the herbage accumulation, through the selection of two representative clumps inside the experimental plots. Each clump had two marked tillers that were identified with a colored plastic ring. The assessment frequency varied according to each season (summer I, autumn, spring, and summer II), started at seven days after harvestings, and weekly proceeded until the subsequent harvesting.

Tillers were classified as aerial and basilar ones, and their leaves as ‘in expansion’, ‘completely expanded’, ‘senescent’ and ‘dead’. Leaves ‘in expansion’ were considered like that when their ligules were not raised. ‘Completely expanded’ leaves were those ones with raised ligules. ‘Senescent’ ones showed less than 50% of senescence, while ‘dead’ leaves showed more than 50%. The number of leaves per tiller (NLT) was obtained by the sum of an average number among ‘in expansion’, ‘expanded’, and ‘senescent’ leaves. ‘Dead’ leaves were not counted.

Leaf blade length (LBL) of ‘in expansion’, ‘completely expanded’, and ‘senescent’ leaves, besides the stem length (SL) of aerial and basilar tillers, were assessed with the aid of a ruler graduated in millimeters. With LBL and SL results was possible to calculate the phyllochron (PHY), leaf elongation rate (LER) and stem elongation rates (SER). At the end of each morphogenesis’ evaluation, 100 tillers from each experimental plot were harvested at 15-cm stubble height, inside a metallic frame of 0.25 m^2. These tillers were similar to those assessed for morphogenesis. They were classified as aerial and basilar tillers and finally fractionated into live or senescent leaf blades, and live stems. These tillers also were measured regarding the length of leaves and stems.

Thereafter, these morphological components were dried in a forced-air oven at 55 °C for 72 hours. After that, the dry mass of each component was divided by its respective length (leaf blades and stems), and these results were used to calculate the gravimetric index. Thereby, a conversion factor (mg mm^{-1}) was obtained for each morphological component and it was used to convert the field measurements (mm tiller^{-1} day^{-1}) in mg tiller^{-1} day^{-1} (CARVALHO et al., 2006). These values were multiplied by the respective tiller population densities (TPD), in order to obtain the estimates of leaves and stems’ growth rates (LGR and SGR, respectively), besides the senescence (SR) and herbage accumulation rate (HAR). The TPD was assessed from three representative clumps of each plot, which all basilar and aerial tillers were counted. All the clumps were also counted from a 3-m^2 useful area, excluding the 0.5-m edge lines. The number of clumps was multiplied by the tillers' average to obtain the TPD.

Data were analyzed by PROC MIXED from SAS® version 9.3 (SAS, 2008), with repeated measures in time. The shading level, season of year and their interactions were considered fixed effects. The variance and covariance matrices were selected by the Akaike's information criterion (AKAIKE, 1974). Means were compared by Tukey's test, and the PROC REG from SAS® analyzed the quantitative data by simple linear regression, at 5% of probability.

RESULTS

Morphogenetic traits like PHY, LER and SER (Table 2) varied in function of an interaction between shading level and season of the year (P<0.05). Lower values of PHY were found out in the spring for FS and SS, besides in summer II for the HS. Regarding the shading levels, there was a positive linear effect on the spring and a negative on summer II.

Table 2. Phyllochron (PHY), leaves (LER) and stems (SER) elongation rates of Tanganyika grass (*Megathyrsus maximus* cv. Tanganyika) under shading levels and seasons of the year.

Season	Shading level^1				SEM	Regression equation	R²
	FS	SS	MS	HF			
	PHY (days leaf^{-1} tiller^1)						
Summer I	9.4^A	6.8^C	7.2^A	7.4^{AB}	0.9	$\hat{Y}$= 7.7^{ns}	-
Autumn	11.4^A	16.0^A	7.2^A	7.4^{AB}	1.3	$\hat{Y}$= 10.5^{ns}	-
Spring	6.6^B	8.4^C	7.6^A	9.2^A	0.7	$\hat{Y}$= 6.896 + 0.0301x*	0.54
Summer II	11.4^A	11.8^B	7.6^A	7.0^B	0.7	$\hat{Y}$= 12.24 - 0.0833x*	0.67
	LER (cm tiller^{-1} day^{-1})						
Summer I	0.38^B	0.47^B	0.58^A	0.49^B	0.06	$\hat{Y}$= 0.48^{ns}	-
Autumn	0.23^B	0.29^B	0.58^A	0.49^B	0.03	$\hat{Y}$= 0.40^{ns}	-
Spring	0.70^A	0.68^A	0.73^A	0.74^A	0.05	$\hat{Y}$= 0.71^{ns}	-
Summer II	0.48^B	0.50^B	0.68^A	0.64^{AB}	0.05	$\hat{Y}$= 0.58^{ns}	-
	SER (cm tiller^{-1} day^{-1})						
Summer I	0.10^B	0.10^B	0.20^A	0.18^B	0.03	$\hat{Y}$= 0.0861 + 0.0019x**	0.73
Autumn	0.10^B	0.04^B	0.20^A	0.18^B	0.02	$\hat{Y}$= 0.0658 - 0.0014x*	0.41
Spring	1.00^A	0.40^A	0.38^A	0.51^A	0.09	$\hat{Y}$= 0.8672 + 0.0084x*	0.62
Summer II	0.19^B	0.24^A	0.30^A	0.31^A	0.04	$\hat{Y}$= 0.1851+ 0.0022x**	0.96

[1] Values respectively described in Table 1 for each season of year. FS: full sun; SS: slight shading; MS: mild shading; HS: heavy shading. The seasons of year occurred between the following dates: summer I from 12/27/2010 to 03/20/2011; spring occurred from 09/02/2011 to 12/20/2011 and summer II from 12/21/2011 to 03/01/2012. X: percentage of shade. Means followed by different letters in the same column are significantly different by Tukey's test (P<0.05). SEM: standard error of the mean. *(P<0.05), **(P<0.01) and ns: non-significant.

Conversely, there was no shading effect ($P>0.05$) in summer I and autumn, with averages of 7.7 and 10.5 days leaf^{-1}, respectively. The LER did not vary in function of the shading levels, regardless of the season of year. Within the seasons, greater rates occurred in spring, excepted by the MS and HS (Table 2). The SER was greater in spring or summer II for FS, SS and HS treatments. There was a positive linear effect of shading levels on the SER in almost all seasons, except in autumn, in which a negative linear effect was observed.

Structural characteristics like LBL, TPD, and SL (Table 3) were affected by the interaction between shading level and the season of the year ($P<0.05$).

Table 3. Number of leaves per tiller (NLT), leaf blade length (LBL), tiller population density (TPD) and stem length (SL) of Tanganyika grass (*Megathyrsus maximus* cv. Tanganyika) under shading levels and seasons of the year.

Season	Shading level^{1}				SEM	Regression equation	R²
	FS	SS	MS	HF			
					NLT (leaves tiller^{-1})		
Summer I	2.3^{B}	2.6^{A}	2.2^{B}	2.3^{B}	0.1	$\hat{Y}= 2.3^{ns}$	-
Autumn	2.4^{B}	1.9^{B}	1.9^{B}	2.3^{B}	0.1	$\hat{Y}= 2.1^{ns}$	-
Spring	3.2^{A}	2.7^{A}	3.0^{A}	2.8^{A}	0.1	$\hat{Y}= 2.9^{ns}$	-
Summer II	2.4^{B}	2.3^{A}	2.2^{B}	2.6^{A}	0.1	$\hat{Y}= 2.4^{ns}$	-
					LBL (cm leaf^{-1})		
Summer I	9.8^{B}	11.2^{C}	12.6^{C}	12.7^{B}	0.9	$\hat{Y}= 9.7971 + 0.0564x^{**}$	0.98
Autumn	12.1^{B}	13.6^{B}	12.6^{C}	12.7^{B}	0.9	$\hat{Y}= 9.7391 + 0.0406x^{**}$	0.99
Spring	20.0^{A}	17.5^{A}	21.7^{A}	24.0^{A}	0.9	$\hat{Y}= 20.8^{ns}$	-
Summer II	12.0^{B}	14.3^{B}	18.6^{B}	$14.\ 9^{B}$	1.0	$\hat{Y}= 11.7 + 1.3x^{*}$	0.38
					TPD (tillers m^{-2})		
Summer I	345^{A}	589^{A}	461^{B}	540^{B}	53	$\hat{Y}= 398.12 + 2.7185x^{*}$	0.38
Autumn	424^{A}	564^{A}	532^{B}	537^{B}	53	$\hat{Y}= 449.05 + 1.4409x^{**}$	0.61
Spring	275^{A}	452^{A}	1196^{A}	1056^{A}	53	$\hat{Y}= 745^{ns}$	-
Summer II	335^{A}	461^{A}	589^{B}	540^{B}	55	$\hat{Y}= 338.8 + 4.2523x^{**}$	0.89
					SL (cm)		
Summer I	60^{A}	51^{A}	43^{C}	40^{B}	2	$\hat{Y}= 60.22 - 0.3721x^{**}$	0.99
Autumn	48^{C}	36^{C}	47^{B}	35^{C}	1	$\hat{Y}= 45.958 - 0.0985x^{*}$	0.22
Spring	54^{B}	45^{B}	59^{A}	51^{A}	2	$\hat{Y}= 52^{ns}$	-
Summer II	60^{A}	52^{A}	41^{C}	40^{B}	1	$\hat{Y}= 60.907 - 0.3778x^{**}$	0.95

[1] Values respectively described in Table 1 for each season of year. FS: full sun; SS: slight shading; MS: mild shading; HS: heavy shading. The seasons of year occurred between the following dates: summer I from 12/27/2010 to 03/20/2011; spring occurred from 09/02/2011 to 12/20/2011 and summer II from 12/21/2011 to 03/01/2012. X: percentage of shade. Means followed by different letters in the same column are significantly different by Tukey's test ($P<0.05$). SEM: standard error of the mean. *($P<0.05$), **($P<0.01$) and ns: non-significant.

There was no effect of shading level on NLT ($P>0.05$). Greater NLT was verified in the spring or summer II for FS, SS, MS and HS treatments. The LBL was greater in spring for all assessed shading levels. The shading provided a positive linear increase for LBL in summer I, autumn and summer II. Greater TDP occurred in the spring for MS and HS (Table 3). Except in the spring, there was a positive linear effect of shading levels on TDP. Greater SL occurred in the spring or summer for FS, SS, MS and HS treatments. There was a negative linear effect on the SL in the function of shading levels, except in the spring.

The LGR, SGR, SR and HAR (Table 4) varied in function of the interaction between shading level and season of year ($P<0.05$). There was a linear positive effect of shading levels on these variables, in almost all seasons, except for SR in the summer II. Greater LGR occurred in the spring or summer II for FS, SS, MS and HS treatments. The SGR was greater in the spring or summer II for FS, SS, MS and HS treatments. The SR was greater in summer II for FS, SS and MS. For the HS treatment, the lowest value was observed in the spring. In general, the HAR values regarded the seasons were greater in the spring or summer II (Table 4).

Table 4. Leaf (LGR) and stem (SGR) growth rates, senescence rate (SR) and herbage accumulation rate (HAR) of Tanganyika grass (*Megathyrsus maximus* cv. Tanganyika) under shading levels and seasons of the year.

Season	Shading level[1]				SEM	Regression equation	R²
	FS	SS	MS	HF			
LGR (kg ha^{-1} dia^{-1} MS)							
Summer I	12^{B}	10^{B}	98^{B}	45^{C}	7	$\hat{Y}= 5.0132 + 1.1504x*$	0.45
Autumn	5^{B}	7^{B}	31^{C}	46^{C}	3	$\hat{Y}= -0.9968 + 0.5137x**$	0.76
Spring	34^{A}	34^{A}	182^{A}	106^{B}	11	$\hat{Y}= 17.616 + 2.0395x**$	0.62
Summer II	32^{A}	73^{A}	165^{A}	180^{A}	14	$\hat{Y}= 19.891 + 2.7644x**$	0.90
SGR (kg ha^{-1} dia^{-1} MS)							
Summer I	3^{B}	1^{B}	8^{B}	15^{C}	2	$\hat{Y}= 0.3468 + 0.2033x**$	0.61
Autumn	3^{B}	1^{B}	7^{B}	15^{C}	2	$\hat{Y}= 0.5668 + 0.1311x*$	0.50
Spring	27^{A}	7^{B}	43^{A}	33^{B}	5	$\hat{Y}= 17.94 + 0.2731x*$	0.24
Summer II	12^{AB}	51^{A}	27^{A}	83^{A}	9	$\hat{Y}= 11.861 + 0.937x*$	0.55
SR (kg ha^{-1} dia^{-1} MS)							
Summer I	1^{B}	1^{B}	44^{B}	12^{A}	5	$\hat{Y}= 1.2772 + 0.5009x*$	0.35
Autumn	3^{B}	1^{B}	7^{D}	12^{A}	2	$\hat{Y}= 0.9733 + 0.1056x*$	0.53
Spring	1^{B}	2^{B}	21^{C}	5^{B}	1	$\hat{Y}= 0.1085 + 0.2102x*$	0.38
Summer II	23^{A}	22^{A}	66^{A}	12^{A}	6	$\hat{Y}= 31^{ns}$	-
HAR (kg ha^{-1} dia^{-1} MS)							
Summer I	14^{B}	10^{C}	62^{C}	48^{B}	3	$\hat{Y}= 6.6371 + 0.8528x**$	0.65
Autumn	5^{C}	7^{C}	31^{D}	49^{B}	3	$\hat{Y}= -1.4033 + 0.5393x**$	0.74
Spring	60^{A}	39^{B}	204^{A}	134^{AB}	27	$\hat{Y}= 35.665 + 2.1024x*$	0.58
Summer II	21^{B}	102^{A}	126^{B}	251^{A}	19	$\hat{Y}= 7.7592 + 3.4997x**$	0.82

[1] Values respectively described in Table 1 for each season of year. FS: full sun; SS: slight shading; MS: mild shading; HS: heavy shading. The seasons of year occurred between the following dates: summer I from 12/27/2010 to 03/20/2011; spring occurred from 09/02/2011 to 12/20/2011 and summer II from 12/21/2011 to 03/01/2012. X: percentage of shade. Means followed by different letters in the same column

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are significantly different by Tukey's test (P<0.05). SEM: standard error of the mean. *(P<0.05), **(P<0.01) and ns: non-significant.

DISCUSSION

Tanganyika grass showed great adaptation regarding the shading, and its phenotypic plasticity was able to adjust its morphogenetic and structural traits (GASTAL & LEMAIRE, 2015). Thereby, the increases of LGR, SGR and HAR corresponded to the increasing shading levels (Table 4). The HAR is a result of growth and senescence rates for individual tillers, besides the TPD at a population level (PAIVA et al., 2011). For all seasons of year and shading levels, the HAR resulted mainly from the LGR, because the stems accumulations were proportionally lower than those of leaves. This occurred due to the critical LAI criterion used to break off the regrowth (EUCLIDES et al., 2010). The regrowth interruption when canopies reach 95% of LI has been standing out as an efficient strategy to control the stem accumulation in swards of tropical grasses (DA SILVA et al., 2015). Many cultivars of *Megathyrsus maximus* Jacq. show a vigorous growth rate, so when they are badly managed, there is a great stem accumulation in the sward (CARNEVALLI et al., 2021). In addition, the environmental variation over the year (Figure 1) affected the HAR (Table 4). In some seasons of the year, as spring and summer I and II, with a high level of precipitation, temperatures, and solar radiation, the tissue turnover is higher (PEREIRA et al., 2010), which also resulted in higher HAR.

At a tiller level, the LGR is dependent on the leaf appearance rate, LER and NLT that indicate the leaf lifespan, jointly with the PHY (GASTAL & LEMAIRE, 2015; CARNEVALLI et al., 2021).

Changes in PHY pattern comparing the spring and the summer II (Table 2) likely occurred due to a difference in climate conditions (Figure 1), which were better in summer II than in spring. The PHY is a variable with great heritability, but environmental factors also influence the plants' growth (CHAPMAN & LEMAIRE, 1993; CARDOSO et al., 2019). These ecological factors likely reduced the PHY when the shading overcame 50% in the spring, besides they caused a negative linear response in summer II. Specifically for this season, the increasing shading levels enhanced the leaf appearance. Thereby, it is evident the ability of Tanganyika grass to adapt itself for shading conditions, considering that the leaf appearance rate is an important morphogenetic trait that influences the tillers' structural characteristics (DA SILVA et al., 2015).

In general, the LER was not affected by the shading levels (Table 2). The spring transits between dry and rainy seasons, and it is a season characterized by the intense plants' renovation in the swards, and great leaf elongation (PAIVA et al., 2011). Considering that, the consistent results of LER also indicate the adaptability of Tanganyika grass in the face of shading environments. Concomitantly, these results suggest that the increases of LGR and HAR in function of the shading levels did not result from the LER, but from other variables that determine the growth rate. The NLT results from the interaction between the speed of consecutive leaves' appearance and the leaves' lifespan (GASTAL & LEMAIRE, 2015;

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CARNEVALLI et al., 2021). In this study, there was no effect of shading levels on this variable (Table 3). Gómez et al. (2016) also did not observe a significant difference in the NLT from Mombaça grass evaluated under full sun and tree shading.

As previously mentioned, shading levels modified the PHY in the spring and summer II (Table 2), which allows concluding (at least in these seasons) that the maintenance of NLT, regardless of the shading level, occurred by an adjustment on leaves' lifespan (CHAPMAN & LEMAIRE, 1993; BALDISSERA et al., 2014). About the seasons of year, there was a linear reduction by 0.0056 leaves tiller^{-1} for each shading increase's percentage unit. For summer I, spring, and summer II, there were no shading level effects, with averages of 2.4, 2.9 and 2.4 leaves tiller^{-1}, respectively.

In general, the LBL increased in the function of the shading levels (Table 3). According to Mitchell & Soper (1958), the number of cell divisions perpendicularly influences the leaf length, as well the LER. Still, according to them, the leaves under shading environments have more cells on the longitudinal axis resulting in longer leaves than those of shade-less environments.

Baldissera et al. (2016) did not find any difference in leaves' lengths of *Megathyrsus maximus* Jacq. Aruana under full sun or shaded by eucalyptus (*Eucalyptus dunnii*), when the swards were managed at 95% of LI. However, the LBL results allow understanding of how the adjustment of this structural trait can be a strategy of the plants to increase HAR in shaded environments. Therefore, the LBL adjustment was another morphogenetic alteration from Tanganyika grass for shading environments. However, the LBL was greater in spring (Table 3), which points out a great effect of climate conditions on this variable.

The increase of SGR in function of the shading levels (Table 4), except in the autumn, resulted from the SER and NLT. The greater values in spring and summer II likely occurred due to the favorable climate conditions (Figure 1), similar to those results verified by Paciullo et al. (2008) when they assessed swards of *Urochloa decumbens*. These authors verified SER 50% greater in spring and summer than those observed in autumn and winter, for both full sun and shading environments. There were a linear positive effect of shading levels on SGR in spring and summer II, with increases by 0.0023 and 0.0016 cm tiller^{-1} day^{-1}, respectively. These increases likely suggest the occurrence of plants' etiolation, a growth process of plants under lighted-less environments, which they stretch their stems to reach the available PAR (BALDISSERA et al., 2014; MARTINS et al., 2021). Conversely, the reduction of SER in autumn could be occurred due to the unfavorable conditions of this season (Figure 1).

A typical response of forage grasses under shading environments is the stem elongation to raise up their leaves, and reduce the light competition (GASTAL & LEMAIRE, 2015; MARTINS et al., 2021). In the present study, this led to greater SER as the shading levels increased, at least in some seasons (Table 2). Nevertheless, this did not reduce the SL (Table 3). Excepted by the spring, the SL was linearly reduced by increasing shading levels. These responses were different from others already observed in studies under similar

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conditions, when the SL increased under shading conditions (PACIULLO et al., 2008; CASTRO et al., 2009; GOBBI et al., 2099; MALAVIYA et al., 2020). Beyond the genetic traits of Tanganyika grass, applying the critical LAI criterion to break off the regrowth also guaranteed a good control of etiolation (DA SILVA & NASCIMENTO JÚNIOR, 2007; DA SILVA et al., 2015).

The TPD is a structural characteristic that allows greater flexibility of adjustment by the plant under different defoliation management and environmental conditions (CARNEVALLI et al., 2021). Alterations on TPD resulted from dynamic processes that constantly occur by the balance between tillers' appearance and death along the year. This balance is influenced by the own forage species, by the environmental conditions and defoliation management (GASTAL & LEMAIRE, 2015; DA SILVA et al., 2015). In the present study, the TPD (Table 3) was modified by the interaction between season of the year and shading level (P<0.05). The greater values were observed in the spring, a season marked by a transition between dry and rainy seasons, as mentioned above (PAIVA et al., 2011). Furthermore, other factors such as the organic reserve from older tillers and the microclimate in the more shaded environments, combined with pasture management by light interception, may have contributed to the increase in TPD in the spring (CARVALHO et al., 2021a). Thereby, except in the spring, there was a linear increase of TPD by the levels of shading (Table 3). This shows again the adaptability of Tanganyika grass to grow in shading conditions. The most common response of swards submitted to shading is exactly to reduce the TPD (MEDINILLA-SALINAS et al., 2013).

Thereby, both the reduction of PHY, the increases of SER (Table 2) and TPD, (Table 3) in the function of increasing shading levels, were morphogenetic and structural traits that ensure the Tanganyika grass the necessary plasticity to increase forage production. The results of LGR, SGR and HAR (Table 4) reinforced this dynamic.

Conversely, the SR increased with the shading levels (Table 4). It is worth pointing out that these results are not beneficial mainly for the nutritional value and forage quality (REIS et al., 2012). However, the increases of LGR and SGR are proportionally greater than those ones of SR, because the HAR was linearly increased by the shading levels (Table 4). The SR likely did not affect the forage nutritional value. Carvalho et al. (2021b) observed a consistent improvement of the Tanganyika grass' chemical composition, in the same experimental conditions and shading levels. The work of these authors was concomitant to our study.

Therefore, the Tanganyika grass is a promisor forage plant to be used in tree shading environments, like those of silvopastoral systems. Based on our results and those available in the literature, Tanganyika grass stands out by its great productive potential and adequate nutritional aspects when it is well managed in shaded environments.

CONCLUSIONS

Shading levels until 70% improves the morphogenetic and structural traits of canopies from Tanganyika grass, and climate conditions from the season of the year influence these characteristics.

Tanganyika grass stands out as an adapted and promisor forage plant to be exploited in production systems with shading environments.

REFERENCES

ALCÂNTARA, P.B.; BUFARAH, G. **Plantas forrageiras: gramíneas e leguminosas**. São Paulo, Nobel, 1980.

ALCÂNTARA, D.; SCHUELER, A.S. Gestão das águas e sustentabilidade: desafios globais e respostas locais a partir do caso de Seropédica, na Região Metropolitana do Rio de Janeiro. **Cadernos Metrópole**, v.17, p.109-126, 2015.

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. de M, SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift,** v.22, n.6, p.711–728. 2013.

AKAIKE, H. A new look at the statistical model identification. **IEEE transactions on automatic control**, v.19, n.6, p.716-723, 1974.

ASSOCIAÇÃO BRASILEIRA DAS INDÚSTRIAS EXPORTADORAS DE CARNES (ABIEC). **Beef report – Perfil da pecuária no Brasil**, 2020. Disponível em: http://abiec.com.br/publicacoes/beef-report-2020/.

BALDISSERA, T.C.; PONTES, L.S.; BARRO, R.S. et al. Phyllochron and leaf lifespan of four C4 forage grasses cultivated in association with trees. **Tropical Grasslands – Forrajes Tropicales**, v.2, p.12-14, 2014.

BALDISSERA, T.C.; PONTES, L.S.; GIOSTRI, A.F. et al. Sward structure and relationship between canopy height and light interception for tropical C4 grasses growing under trees. **Crop and Pasture Science**, v.67, n.11, p.1199-1207, 2016.

CARDOSO, R.R.; SOUSA, L.F.; FERREIRA, A.C.H. et al. Short-term evaluation of Massai grass forage yield and agronomic characteristics and sheep performance under rotational grazing with different pre-grazing canopy heights. **Semina: Ciências Agrárias**, v.40, n.3, p.1339-1356, 2019.

CARNEVALLI, R.A.; CONGIO, G.F.S; SBRISSIA, A.F. et al. Growth of Megathyrsus maximus cv. Mombaça as affected by grazing strategies and environmental seasonality. II. Dynamics of herbage accumulation. **Crop and Pasture Science**, v.72, n.1 p.66-72, 2021.

CARRÈRE, P.; LOUAULT, F.; SOUSSANA, J.F. Tissue turnover within grass-clover mixed swards grazed by sheep. Methodology for calculating growth, senescence and intake fluxes. **Journal of Applied Ecology**, v.34, n.2, p.333-348, 1997.

CARVALHO, C.A.B.; PACIULLO, D.S.C.; ROSSIELO, R.O.P. et al. Dinâmica do perfilhamento em capim-elefante sob influência da altura do resíduo pós-pastejo. **Pesquisa Agropecuária Brasileira**, v.41, p.145-152, 2006.

CARVALHO, B.H.R.; MARTUSCELLO, J. A.; ROCHA, G.O. et al. Tillering dynamics in spring and summer of marandu palisade grass

cc BY

pastures previously used under deferred grazing. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v.73, p.1422-1430, 2021a.

CARVALHO, C.A.B.; SILVA, P.H.F.; ZANELLA, P.G. Chemical composition of Tanganyika grass under tree shading levels in a silvopastoral system. **Revista Brasileira de Saúde e Produção Animal**, v.22, e2122112021, 2021b.

CASTRO, C.R.T.; PACIULLO, D.S.C.; GOMIDE, C.A.M. et al. Características agronômicas, massa de forragem e valor nutritivo de *Brachiaria decumbens* em sistema silvipastoril. **Pesquisa Florestal Brasileira**, n.60, p.19-25, 2009.

CHAPMAN, D.F.; LEMAIRE, G. Morphogenetic and structural determinants of plant regrowth: regrowth after defoliation. In*:* BACKER M. J. (Ed.) **Grasslands for our world.** Wellington: SIR Publishing, 1993, p.55-64.

DA SILVA, S. C.; NASCIMENTO JR., D. Avanços na pesquisa com plantas forrageiras tropicais em pastagens: características morfofisiológicas e manejo do pastejo. **Revista Brasileira de Zootecnia**, v.36, Suplemento especial, p.121-138, 2007.

DA SILVA, S.C.; SBRISSIA, A.F.; PEREIRA, L.E.T. Ecophysiology of C_4 forage grasses—understanding plant growth for optimising their use and management. **Agriculture**, v.5, n.3, p.598-625, 2015.

EUCLIDES, V.P.B.; VALLE, C.B.; MACEDO, M.C.M. et al. Brazilian scientific progress in pasture research during the first decade of XXI century. **Revista Brasileira de Zootecnia**, v.39, supl. especial, p.151–168, 2010.

GASTAL, F.; LEMAIRE, G. Defoliation, shoot plasticity, sward structure and herbage utilization in pasture: Review of the underlying ecophysiological processes. **Agriculture**, v. 5, n. 4, p. 1146-1171, 2015.

GOBBI, K.F.; GARCIA, R.; GARCEZ NETO, A.F. et al. Características morfológicas, estruturais e produtividade do capim-braquiária e do amendoim forrageiro submetidos ao sombreamento. **Revista Brasileira de Zootecnia**, v.38, n.9, p.1645-1654, 2009.

GÓMEZ, M.; NAVARRO-MEJÍA, O.; PÉREZ-CORDERO, A. Evaluacion de la frecuencias de corte del pasto guinea mombaza (Megathyrsus maximus, Jacq), en condiciones de sol y sombra natural en el municipio de Sampués, Sucre-Colombia. **Revista Colombiana de Ciencia Animal**, v.8, p.283-292, 2016.

INSTITUTO NACIONAL DE METEOROLOGIA (INMET). **Dados Climatológicos, Estação Automática de Seropédica**, 2013. Disponível em: http://www.inmet.gov.br.

LEMAIRE, G. HODGSON, J.; CHABBI, A. (Ed.). **Grassland productivity and ecosystem services**. Oxford: CABI, 2011.
LIMA, H.N.; DUBEUX JÚNIOR; J.C.B.; SANTOS, M.V. et al. Herbage responses of signalgrass under full sun or shade in a silvopasture system using tree legumes. **Agronomy Journal**, v.112, n.3, p.1-10, 2020.

LIMA, M.A.; PACIULLO, D.S.C.; MORENZ, M.J.F. et al. Productivity and nutritive value of Brachiaria decumbens and performance of dairy heifers in a long-term silvopastoral system. **Grass and Forage Science**, v.74, n.1, p.160-170, 2018.

MALAVIYA, D.R.; BAIG, M.J.; KUMAR, B. et al. Effects of shade on guinea grass genotypes Megathyrsus maximus (Poales: Poaceae). **Revista de Biología Tropical**, v.68, n.2, p.563-572, 2020.

MARTINS, C.D.; SCHMITT, D.; DUCHINI, P.G. et al. Defoliation intensity and leaf area index recovery in defoliated swards: implications for forage accumulation. **Scientia Agricola**, v.78, 2021.

MARTUSCELLO, J.A.; JANK, L.; GONTIJO NETO, M.M. et al. Produção de gramíneas do gênero *Brachiaria* sob níveis de sombreamento. **Revista Brasileira de Zootecnia**, v.38, n.7, p.1183-119, 2009.

MEDINILLA-SALINAS, L.; VARGAS-MENDOZA, M.C; LÓPEZ-ORTIZ, S. et al. Growth, productivity and quality of *Megathyrsus maximus* under cover from *Gliricidia sepium*. **Agroforestry Systems,** v.87, n.4, p.891–899, 2013.

MITCHELL, K.J.; SOPER, K. Effects of differences in light intensity and temperature on the anatomy and development of leaves of *Lolium perenne* and *Paspalum dilatatum*. **New Zealand Journal of Agricultural Research**, v.1, n.1, p.1-16, 1958.

PACIULLO, D.S.C.; CAMPOS, N.R.; GOMIDE, C.A.M. et al. Crescimento do pasto de capim braquiária influenciado pelo nível de sombreamento e pela a estação do ano. **Pesquisa Agropecuária Brasileira**, v.43, n.7, p.317-323, 2008.

PACIULLO, D.S.C.; GOMIDE, C.D.M.; CASTRO, C.R.T. Morphogenesis, biomass and nutritive value of Panicum maximum under different shade levels and fertilizer nitrogen rates. **Grass and Forage Science,** v.7, n.3, p.590-600, 2017.

PACIULLO, D.S.C.; FERNANDES, P.B.; CARVALHO, C.A.B. et al. Pasture and animal production in silvopastoral and open pasture systems managed with crossbred dairy heifers. **Livestock Science**, v.1, p.104426, 2021.

PAIVA, A.J.; DA SILVA, S.C.; PEREIRA, L.E.T. et al. Morphogenesis on age categories of tillers in marandu palisadegrass. **Scientia Agricola**, v.68, p.626-631, 2011.

PEREIRA, J.C.; GOMES, F.K.; OLIVEIRA, M.D.B.L. et al. Defoliation management affects morphogenetic and structural characteristics of mixed pastures of brachiaria grass and forage peanut. **African Journal of Range & Forage Science**, v.34, n.1, p.13-19, 2017.

PEREIRA, L.E.T.; PAIVA, A.J.; SILVA, S.C.D. et al. Sward structure of marandu palisadegrass subjected to continuous stocking and nitrogen-induced rhythms of growth. **Scientia Agricola**, v.67, p.531-539, 2010.

REIS, R.A.; RUGGIERI, A.C.; OLIVEIRA, A.A. et al. Suplementação

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como estratégia de produção de carne de qualidade em pastagens tropicais. **Revista Brasileira de Saúde Produção Animal**, v.13, n.3, p.642-655, 2012.

SANTIAGO-HERNÁNDEZ, F.; LÓPEZ-ORTIZ, S.; ÁVILA-RESÉNDIZ, C. et al. Physiological and production responses of four grasses from the genera Urochloa and Megathyrsus to shade from Meliaazedarach L. **Agroforestry Systems**, v.90, n.2, p.339-349, 2016.

STATISTICAL ANALYSIS SYSTEM [SAS]. **SAS/STAT User's guide, Version 9.3**. Cary, NC: SAS Institute Inc, 2008.

VICTOR, D.M.; JANK, L.; LEMPP, B. et al. Selection of full-sib families of Panicum maximum Jacq under low light conditions. **Revista Ceres**, v.62, n.2, p.199-207, 2015.

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