doi: 10.17138/TGFT(9)256-267

Research Paper

Effects of stubble height and season of the year on morphogenetic, structural and quantitative traits of Tanzania grass

Efectos de la altura residual y de la estación del año en las características morfogénicas, estructurales y cuantitativas del pasto Tanzania

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Abstract

The objective of this study was to evaluate regrowth period (RP), morphogenetic, structural and productive characteristics of the guinea grass cultivar Tanzania [*Megathyrsus maximus* (syn. *Panicum maximum*)] under different stubble heights (SH) during dry (DS) and rainy (RS) seasons in the eastern Amazon region. The treatments were: 5, 15, 25, 35, 45 and 55 cm SH, distributed in a randomized complete block design with 6 replicates. In the 2 seasons, RP decreased linearly with increase in SH, and was considerably shorter in the RS (47 d). Leaf appearance rate decreased linearly from 0.071 to 0.051 leaves/tiller/d with increasing SH, and it was higher during the RS. Increase in SH increased leaf elongation rate, stem elongation rate and leaf area index. In the RS, climatic conditions favored the morphogenesis, resulting in higher herbage accumulation (8,693 kg DM/ha) than in the DS (2,597 kg DM/ha). In associating seasons with SH, we recommend that Tanzania grass be managed at SH between 35 and 45 cm in the DS, resulting in RP from 61 to 64 days, and at SH of 35 cm in the RS, resulting in RP of 41 days. Studies to test this management strategy seem warranted.

Keywords: Amazon biome, dry season, herbage accumulation, *Megathyrsus maximus*, rainy season.

Resumen

En el estudio se evaluaron el período de rebrote (RP), las características morfogénicas, estructurales y productivas de pasturas de Tanzania [*Megathyrsus maximus* (syn. *Panicum maximum*)] en diferentes alturas de rastrojo (SH) y estaciones del año, estación seca (DS) y estación lluviosa (RS) en la región Amazónica oriental. Los tratamientos incluyeron cinco SH: 15; 25; 35; 45 y 55 cm en un diseño de bloques completamente al azar con seis repeticiones. En las dos estaciones el RP disminuyó linealmente con el aumento de SH, y fue considerablemente menor en la RS (47 d). La tasa de aparición de hojas disminuyó linealmente de 0.071 a 0.051 hojas/macolla/d con el aumento de SH, y fue mayor durante la RS. El aumento en SH proporcionó aumento en la tasa de alargamiento de hoja, en la tasa de alargamiento del tallo, y en el índice de área foliar. En la RS, las condiciones climáticas favorecieron la morfogénesis del cultivar Tanzania, lo que resultó en mayor acumulación de forraje (8,693 kg DM/ha) que DS (2,597 kg DM/ha). En la asociación de estaciones con SH, recomendamos que pasturas de Tanzania se maneje en SH entre 35 y 45 cm en DS, correspondiente a RP de 61 a 64 días, y en el SH de 35 cm en la RS, correspondiente a RP de 41 días. Los estudios para probar esta estrategia de gestión parecen justificados.

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Palabras clave: Acumulación de biomasa, Amazonia oriental, época lluviosa, época seca, *Megathyrsus maximus.*

Introduction

In aiming to intensify pasture management, producers in Brazil largely use cultivars of guinea grass [*Megathyrsus maximus* (syn. *Panicum maximum*)], a species of African origin well adapted to tropical conditions. A cultivar widely used is Tanzania, due to its favorable traits such as high production potential and nutritional value (Paciullo et al. 2016). However, this cultivar is also very demanding in terms of soil fertility (Pezzopane et al. 2016) and management owing to its high stem elongation rates, notably near flowering time.

Tanzania grass pastures have gained prominence in the Amazon biome thanks to the expansion of Brazilian livestock to this region, despite very strict environmental laws (Nascimento et al. 2019). Thus, many concerns arise regarding the management of this forage plant due to the different soil-climatic conditions found in the region, such as highly acidic, phosphorus-poor and high-water-table soils, annual precipitation above 2,000 mm, plus minimum temperature above 20 °C and availability of light during most of the year.

In addition to the soil-climatic peculiarities of the region that influence herbage production, it is important to understand how grasses respond to the intensity/severity (Silva et al. 2016, 2019; Gomide et al. 2019) and frequency of defoliation (Moura et al. 2017; Pedreira et al. 2017) under the specific conditions mentioned above. Defoliation frequency can be determined based on light interception (LI) by the canopy, which, according to recent research (Pedreira et al. 2017; Tesk et al. 2018; Silva et al. 2019), has shown potential for use when the level of 95% is adopted. At this stage pastures are considered to have high proportions of leaves and low proportions of stem and dead material in the herbage mass, in addition to better quality (Brougham 1956; Korte et al. 1982; Parsons et al. 1988).

Defoliation intensity/severity can be predefined based on stubble height (SH) and is widely used in research on forage plants in tropical (Silva et al. 2016; Pereira et al. 2018; Gomide et al. 2019; Tesk et al. 2020) and temperate regions (Kohmann et al. 2017; Insua et al. 2020). As such, it has become a management tool on many farms. However, studies on effects of SH on morphology and forage production in pastures in Brazil have been located in regions where soil-climatic characteristics are very different from those encountered in the Amazon biome. This reinforces the need for studies like the present one, which may assist in decision-making in the field with a view to optimizing pasture use and, consequently, reducing environmental impacts in the region.

The hypothesis tested in this experiment was that, when associated with differing SH following harvesting, climatic conditions typical of the Amazon region (precipitation regime, mainly) affect both the structure and production of Tanzania grass. Therefore, the objective of this study was to examine the morphogenetic and structural traits and herbage production of *Megathyrsus maximus* cv. Tanzania managed under 5 different SHs throughout an experimental year in the eastern Amazon region.

Material and Methods

Experimental site

The experiment was conducted on the experimental farm at the Federal Rural University of the Amazon (UFRA), located in Igarapé-Açu, Pará, Brazil (01º07'21” S, 47º36'27” W; 50 masl), from August 2017 to August 2018, in plots of Tanzania grass established in 2014. The soil is classified as a Yellow Latosol (Oxisol) with a sandy-loam texture and a low slope gradient. Soil analysis performed in the 0 20 cm layer revealed the following chemical characteristics: pH ($CaCl_2$) = 4.7; organic matter = 7.98 g/kg; P (ion-exchange resin extraction method) = 1.54 mg/dm^3; K = 3.0 mmolc/dm^3; Ca = 28.0 mmolc/dm^3; Mg = 28.0 mmolc/dm^3; H + Al = 47.2 mmolc/dm^3; cation-exchange capacity = 106.2 mmolc/dm^3; and base saturation = 55.7%.

The local climate is classified as a tropical monsoon (Am) type according to the Köppen classification, with a short dry season and heavy rains during the rest of the year. Total precipitation during the experimental period was 2,270 mm, consisting of 130 mm from September to December 2017 and negative soil water balance (96 to 175 mm monthly deficit) (characterized as the dry season, DS), and 2,140 mm from January to August 2018 (rainy season, RS) with positive soil water balance from February to July (15–380 mm monthly surplus) (Table 1). Mean temperature during the experimental period was 27.5 °C.

Experimental design and management

Treatments consisted of 5 Tanzania grass stubble heights (SH: 15, 25, 35, 45 and 55 cm) evaluated for a full year with data separated into dry (DS) and rainy (RS) seasons.

The experiment was laid out as a randomized complete block design with 6 replicates, in a total of thirty 3 × 4 m experimental units spaced 1 m apart.

Table 1. Monthly rainfall and water balance in Igarapé-Açu, PA, Brazil.

Month	Precipitation (mm)		Soil water balance (mm)
	Climate mean (1994–2017)	Experimental period (2017–2018)	
Sep	44.7	34.2	-98
Oct	22.0	17.1	-152
Nov	18.5	0.0	-175
Dec	96.6	78.9	-96
Jan	236.1	153.3	0
Feb	308.0	514.4	380
Mar	456.7	303.4	125
Apr	389.4	408.8	255
May	258.5	381.8	245
Jun	199.6	146.3	20
Jul	155.0	134.8	15
Aug	62.4	97.2	1

In June 2017, still in the RS, the various plots were harvested at the appropriate stubble heights for implementation of the study. Subsequently, plots received the equivalent K dose of 100 kg/ha in the form of KCl plus 200 kg N/ha in the form of urea divided into 3 equal applications (January, March and May 2018). After this harvest, light interception (LI) by the canopy in each plot was monitored using the AccuPAR LP-80 canopy analyzer (Decagon®) throughout the regrowth period of the grass, with readings taken daily at 3 points per plot, until the canopy reached 95% LI. Upon reaching 95% LI, the plots were harvested at the appropriate SH (treatments) using a mower.

The harvest intervals in the plots and the number of harvest events, according to the SH and the evaluation periods, are shown in Table 2. The total number of harvest events was determined by the length of the regrowth period (RP) in each treatment, i.e. time to reach 95% LI. Regrowth period was calculated as the time (days) between one harvest and the subsequent one.

Morphogenetic and structural traits

Leaf blades and stems were measured on 5 tillers per plot, once weekly, during the regrowth period. After each harvest, 5 new tillers were selected.

All leaves of each tiller were numbered and classified as expanded (with the ligule visible), expanding (no visible ligule) or senescent (when the end of the leaf blade showed some sign of senescence). Leaves with more than 50% of the blade length compromised by senescence were considered dead. In the expanded leaves, length was measured from the tip of the blade to its ligule. For expanding leaves, length was measured from the tip of the blade to the ligule of the youngest fully expanded leaf. In the case of senescent leaves, length of the green leaf blade was measured from the ligule to the point where senescent tissue was visible. The length of stem plus sheath was measured from ground level to the ligule of the last fully expanded leaf.

The data were used to estimate the rates of leaf appearance (LAR, leaves/tiller/d), leaf elongation (LER, cm/tiller/d), stem elongation (SER, cm/tiller/d) and leaf senescence (LSR, cm/tiller/d) for each tiller. The number of live leaves per tiller (NLL) was also determined by direct counting. Leaf lifespan (LLS, days) was determined using the values of LAR and NLL per tiller (Lemaire and Chapman 1996). Phyllochron (PHY, days/leaf) was calculated as the inverse of LAR. Final leaf size (FLS, cm) was determined as the length of expanded leaf blades. Leaf and stem elongation rates and LSR were obtained by dividing the difference between the final and initial lengths of the green or senescent leaf blades or stems, by the number of days in the regrowth period. Leaf appearance rate was calculated by dividing the number of expanded leaves per tiller by the number of days in the regrowth period.

Height of forage in plots in pre-harvest condition was measured whenever the plot reached 95% LI, at 5 points per plot, using centimeter-graded rules. The indirect leaf area index (LAI) was also determined in the pre-harvest condition using the AccuPAR PAR/LAI LP-80 canopy analyzer (Decagon®). Readings were taken at 3 points per plot along with the measurement of LI.

Table 2. Duration of dry and rainy seasons and number of harvest events (in parentheses) of Tanzania grass for different stubble height (SH) treatments in Igarapé-Açu, PA, Brazil.

SH (cm)	Season of the year		Total harvest events
	Dry	Rainy	
15	10 Sep – 31 Dec 2017 (1)	01 Jan – 04 Aug 2018 (3)	4
25	20 Sep – 31 Dec 2017 (1)	01 Jan – 03 Aug 2018 (4)	5
35	01 Sep – 31 Dec 2017 (2)	01 Jan – 10 Aug 2018 (5)	7
45	01 Sep – 31 Dec 2017 (2)	01 Jan – 05 Aug 2018 (5)	7
55	01 Sep – 31 Dec 2017 (3)	01 Jan – 06 Aug 2018 (7)	10

Tiller population density (TPD) was evaluated whenever the plots intercepted 95% of light. For this assessment, the total number of live tillers within a 1 m × 0.5 m frame per plot was counted and the result expressed as number of tillers per square meter.

Tiller demography was evaluated in a single tussock per plot. Immediately after the grass was cut to implement the SH, the tillers present in the tussock were counted. These tillers were marked and termed 'zero-generation tillers' (G0). At the subsequent harvest, live tillers from G0 were counted, and new emerged tillers, termed 'generation-one tillers' (G1), were marked. The total number of dead tillers was always counted in each evaluation cycle until the end of the experimental period. Tiller counts were made successively, totaling 5, 6, 8, 8 and 10 generations for SHs of 15, 25, 35, 45 and 55 cm, respectively. From the obtained data, the following variables were calculated and expressed as tillers/100 tillers per regrowth period, following Bahmani et al. (2003): tiller appearance rate (TAR) = number of emerged tillers divided by the number of existing tillers at the previous marking event; tiller mortality rate (TMR) = number of dead tillers divided by the number of existing tillers at the previous marking event; and tiller survival rate (TSR) = number of remaining tillers divided by the number of tillers existing at the previous marking event.

Herbage accumulation and morphological composition

Herbage accumulation above the SH was measured by collecting the herbage within a 1 m × 0.5 m quadrat per plot whenever the canopy reached 95% LI. The collected samples were halved: one half being used to determine DM concentration, and the other for a manual separation of the morphological components, namely: leaf blade (LB), stem + sheath (ST) and dead material (DeM). Samples were then weighed and dried in a forced-air oven at 60 °C for 72 h, and the proportions of each morphological component were calculated based on the weight of the components. Herbage accumulation was calculated for each harvest cycle and, at the end of each period, all accumulations were summed, generating the total herbage in each period (THA).

Statistical analysis

Data were analyzed using the PROC MIXED procedure of SAS software (SAS Institute Inc. 2008). The model used for all studied variables contained the effects of SH, season of the year and their interactions, which were considered fixed effects, whereas the blocks (replicates) and their interactions were considered random effects. The procedure of repeated measures over time was used with the variance components as a covariance structure. Treatment means were considered different and interactions significant when P≤0.05. Polynomial orthogonal contrasts were used when SH effects were observed. Means as a function of seasons were compared by the F-test.

Results

There was no significant interaction effect (P>0.05) between SH and season for the length of the regrowth period (RP) (Table 3). The RP decreased linearly with increase in SH and was considerably shorter in the RS than in the DS (P≤0.05).

Morphogenetic and structural traits

There was a significant interaction effect between SH and season (P≤0.05) for the morphogenetic variables LLS and SER. LAR, PHY and LER variables were influenced by both SH and season (P≤0.05), whereas LSR was influenced by SH only (Table 4).

Table 3. Effects of stubble height and season of the year on the duration of the regrowth period (RP) of Tanzania grass (*Megathyrsus maximus*) in Igarapé-Açu, PA, Brazil.

Season	Stubble height (cm)					Effect	Mean	s.e.
	15	25	35	45	55			
			Regrowth period (d)					
Dry	115.6	96.3	64.1	61.4	59.6		79.3a	1.15
Rainy	71.1	53.7	41.2	40.7	29.4		47.3b	0.68
Mean	93.1	75.0	52.6	51.2	44.6	L (<0.0001)		
s.e.	1.32	1.21	1.21	1.21	1.28			

Within stubble heights seasonal means followed by different letters are different (P≤0.05).
L: observed significance level for linear effects of SH.

Table 4. Effects of stubble height and season of the year on leaf appearance rate (LAR), leaf elongation rate (LER), phyllochron (PHY), leaf senescence rate (LSR), leaf lifespan (LLS) and stem elongation rate (SER) of Tanzania grass (*Megathyrsus maximus*) in Igarapé-Açu, PA, Brazil.

Season	Stubble height (cm)					Effect	Mean	s.e.
	15	25	35	45	55			
				LAR (leaves/tiller/d)				
Dry	0.063	0.051	0.048	0.058	0.053		0.050b	0.003
Rainy	0.080	0.068	0.060	0.058	0.050		0.064a	0.002
Mean	0.071	0.059	0.054	0.058	0.051	L (<0.0001)		
s.e.	0.003	0.003	0.004	0.003	0.004			
				LER (cm/tiller/d)				
Dry	1.45	1.60	1.67	2.22	2.38		1.86b	0.239
Rainy	2.92	3.29	3.60	3.37	3.97		3.43a	0.239
Mean	2.18	2.44	2.64	2.79	3.18	L (<0.0001)		
s.e.	0.234	0.234	0.247	0.234	0.247			
				PHY (d/leaf)				
Dry	15.87	19.61	20.83	17.24	18.87		18.48a	1.60
Rainy	12.50	14.71	16.67	17.24	18.87		15.99b	1.50
Mean	14.09	16.95	18.52	17.24	18.87	L (<0.0001)		
s.e.	1.58	1.58	1.50	1.58	1.50			
				LSR (cm/tiller/d)				
Dry	0.138	0.152	0.217	0.269	0.353		0.226	0.025
Rainy	0.114	0.193	0. 239	0.307	0.363		0.243	0.026
Mean	0.126	0.172	0.228	0.288	0.358	Q (<0.0001)		
s.e.	0.060	0.060	0.036	0.036	0.025			
				LLS (d)				
Dry	69.49a	58.72a	45.01a	42.78a	41.85a	Q (0.0201)	51.56	1.44
Rainy	44.44b	37.93b	35.69b	35.18b	24.73b	L (<0.0001)	35.59	0.74
Mean	56.94	48.32	40.35	38.98	33.29			
s.e.	2.062	1.618	1.618	1.618	1.618			
				SER (cm/tiller/d)				
Dry	0.060a	0.069a	0.074b	0.075b	0.052b	NS	0.065	0.007
Rainy	0.071a	0.091a	0.104a	0.117a	0.138a	L (0.0079)	0.100	0.006
Mean	0.065	0.080	0.089	0.096	0.095			
s.e.	0.011	0.011	0.011	0.011	0.011			

Within stubble heights means for seasons followed by different letters are different (P≤0.05).
L, Q: observed significance level for linear and quadratic effects of SH, respectively.

Leaf appearance rate decreased linearly with increasing SH (P≤0.05) and overall was greater during the RS than during the DS (0.064 vs. 0.050 leaves/tiller/d) (Table 4). In contrast, average LER increased linearly as SH increased but was greater during the RS than during the DS (3.43 vs. 1.86 cm/leaf/d). Phyllochron increased linearly with increase in SH (P≤0.05), since LAR declined linearly, and was longer during the DS than in the RS (18.48 vs. 15.99 d/leaf).

Leaf senescence rate increased quadratically (P≤0.0001) with increase in SH, with no significant effect of season. Leaf lifespan decreased with increasing SH, the response being quadratic during the DS (P≤0.05) and linear during the RS (P≤0.0001). On average, LLS was greater during the DS of the year at all SHs (P≤0.05). Stem elongation rate was not significantly affected by SH during the DS (P>0.05) but increased linearly (P≤0.05) with increase in SH during the RS. For SH of 35, 45 and 55 cm, SER was higher during the RS than during the DS (P≤0.05) (Table 4).

In the analysis of structural traits (Table 5), a significant interaction effect between SH and season (P≤0.05) was observed for FLS and NLL. Final leaf size increased linearly with increasing SH during the DS (P≤0.05) with no effect of SH during the RS. Leaves were larger (P≤0.05) during the RS at all SHs except 55 cm. Number of live leaves decreased with increasing SH in both seasons, linearly (P≤0.05) during the DS and quadratically (P≤0.05) during the RS. At SHs of 35, 45 and 55 cm, NLL was higher in the RS than in the DS

(Table 5). Tiller population density was affected only by SH (P≤0.05), decreasing quadratically as SH increased (P≤0.05). In the pre-harvest condition, i.e. upon reaching 95% LI, canopy height was not altered (P>0.05) by SH or season. Average height of Tanzania grass at 95% LI was 75.0 ± 0.40 cm in the DS and 76.5 ± 0.46 cm in the RS. Leaf area index rose linearly with increasing SH (P≤0.05), ranging from 2.78 in the plots managed at 15 cm to 3.97 in those managed at SH of 55 cm (Table 5).

As regards tiller demographic variables, a significant interaction effect between SH and season (P≤0.05) was detected for tiller mortality rate (TMR) (Table 6). A linear reduction in TMR was observed as SH increased in both seasons (P≤0.05). For most SHs TMR was higher in the RS but differences were significant (P≤0.05) only for 15 and 25 cm SH. Tiller appearance rate also decreased linearly with increasing SH (P≤0.05) and was higher during the RS than in the DS. TSR also increased linearly with increase in SH (P≤0.05) in both seasons and was higher during the DS than in the RS (67.5 vs. 60.3%) (Table 6).

Herbage accumulation and morphological composition

There was a significant interaction effect between SH and season for proportions of leaf blade and dead material (P≤0.05). Isolated effects of SH (P≤0.05) and season of the year (P≤0.05) were detected for THA and stem + sheath (Table 7).

Total herbage accumulation decreased linearly with increase in SH in both seasons (P≤0.05). Only about 22% of THA occurred in the DS (P≤0.05) (Table 7).

Leaf blade proportion increased linearly (P≤0.05) with increase in SH in both seasons (Table 7). While leaf proportion was greater (P≤0.05) in the DS than the RS at 15 cm SH, at 55 cm SH the reverse was the case. During the RS, DeM proportion decreased linearly with increasing SH but showed a quadratic response during the DS (P≤0.05). ST proportion responded quadratically to increasing SH (P≤0.05), and at the height of 55 cm this component was not found in the samples of herbage accumulated above the residual stubble. Stem + sheath percentage was higher in the RS (6.21%) than in the DS (5.38%).

Table 5. Effects of stubble height and season of the year on final leaf size (FLS), number of live leaves (NLL), tiller population density (TPD) and leaf area index (LAI) of Tanzania grass (*Megathyrsus maximus)* in Igarapé-Açu, PA, Brazil.

Season	Stubble height (cm)					Effect	Mean	s.e.
	15	25	35	45	55			
				FLS (cm)				
Dry	24.1b	25.6b	28.3b	28.3b	31.7a	L (0.0003)	27.6	1.16
Rainy	35.0a	30.9a	33.4a	34.6a	33.9a	NS	33.6	1.18
Mean	29.6	28.2	30.8	31.4	32.8			
s.e.	1.22	1.15	1.15	1.15	1.15			
				NLL				
Dry	3.82a	3.64a	3.33b	3.02b	2.67b	L (<0.0001)	3.29	0.08
Rainy	3.81a	3.85a	3.97a	3.78a	3.19a	Q (0.0235)	3.72	0.08
Mean	3.81	3.74	3.65	3.40	2.93			
s.e.	0.11	0.10	0.09	0.09	0.09			
				TPD (tillers/m²)				
Dry	264	258	260	234	224		228	3.60
Rainy	272	274	276	220	222		232	3.22
Mean	268	266	268	228	224	Q (0.0295)		
s.e.	6.34	5.36	5.08	5.08	5.08			
				LAI				
Dry	2.63	3.27	3.64	3.96	4.02		3.50	0.08
Rainy	2.93	3.27	3.65	3.67	3.91		3.55	0.03
Mean	2.78	3.43	3.64	3.86	3.97	L (<0.0001)		
s.e.	0.09	0.09	0.09	0.09	0.09			

Within stubble heights means followed by different letters are different (P≤0.05).
L, Q: observed significance level for linear and quadratic effects of SH, respectively.

Table 6. Effects of stubble height and season of the year on tiller mortality rate (TMR), tiller appearance rate (TAR) and tiller survival rate (TSR) of Tanzania grass (*Megathyrsus maximus*) in Igarapé-Açu, PA, Brazil.

Season	Stubble height (cm)					Effect	Mean	s.e.
	15	25	35	45	55			
			TMR (tillers/100 tillers)					
Dry	42.4b	31.0b	27.2a	26.0a	23.8a	L (0.0005)	30.3	1.14
Rainy	58.9a	44.5a	36.4a	35.3a	23.4a	L (<0.0001)	39.7	1.03
Mean	50.7	37.7	31.8	30.6	23.6			
s.e.	2.04	1.63	1.63	1.63	1.63			
			TAR (tillers/100 tillers)					
Dry	37.9	31.0	30.9	31.9	22.1		30.5b	1.73
Rainy	58.7	49.0	39.1	39.1	28.8		42.9a	1.70
Mean	48.3	40.0	35.0	35.5	25.4	L (<0.0001)		
s.e.	2.69	2.83	2.69	2.69	2.69			
			TSR (tillers/100 tillers)					
Dry	46.6	68.1	72.8	74.0	76.2		67.5a	1.69
Rainy	41.1	55.5	63.6	64.7	76.6		60.3b	0.87
Mean	43.8	61.8	68.2	69.4	76.4	L (<0.0001)		
s.e.	2.41	2.22	2.22	2.22	2.22			

Means followed by different letters comparing the effect of seasons are different (P≤0.05).
L: observed significance level for linear effects of SH

Table 7. Effects of stubble height and season of the year on total herbage accumulation (THA) and leaf blade (LB), dead material (DeM) and stem (ST) proportions of Tanzania grass (*Megathyrsus maximus*) in Igarapé-Açu, PA, Brazil.

Season	Stubble height (cm)					Effect	Mean	s.e.
	15	25	35	45	55			
			THA (kg DM/ha)					
Dry	3,503	2,671	2,510	2,304	1,647		2,527b	125
Rainy	10,142	9,262	8,664	7,913	7,482		8,693a	187
Mean	6,822	5,966	5,587	5,109	4,565	L (<0.0001)		
s.e.	197	179	197	197	197			
			LB (g/kg DM)					
Dry	611a	762a	780a	777a	793b	L (0.0004)	745	16.0
Rainy	561b	756a	798a	833a	857a	L (<0.0001)	761	12.0
Mean	587	759	789	805	825			
s.e.	17.5	16.2	16.2	16.2	16.2			
			DeM (g/kg DM)					
Dry	201a	198a	163a	163a	209a	Q (<0.0001)	187	10.0
Rainy	228a	167a	166a	154a	142b	L (<0.0001)	172	10.0
Mean	215	183	165	159	176			
s.e.	15.8	15.8	15.8	15.8	15.8			
			ST (g/kg DM)					
Dry	182	45.9	32.5	9.8	0.0		53.8b	3.1
Rainy	198	59.5	39.7	12.8	0.0		62.1a	3.1
Mean	190	52.7	36.1	11.3	0.0	Q (<0.0001)		
s.e.	8.2	8.2	8.2	8.2	0.0			

Means followed by different letters comparing the effect of seasons are different (P≤0.05).
L: observed significance level for linear effects of SH

Discussion

Shorter regrowth periods in pastures managed during the RS, as compared with the DS, are mainly due to contrasting climatic conditions between the seasons. Tillering is directly affected by the light intercepted by the canopy (Paciullo et al. 2016), as well as by changes in temperature and water availability (Tilley et al. 2019), which was highly contrasting between the two seasons. Environmental conditions adverse to tiller development lead to less herbage accumulation after harvest (Table 7), causing plants to expend more time and larger amounts of reserves to re-intercept 95% LI (Silva et al. 2019). In this study, we observed that differences in regrowth period between the two seasons declined as SH was increased up to 45 cm. For instance, at SH of 15 cm the difference between seasons in regrowth period was 44.5 days, whereas at 45 cm this difference was only 20.7 days.

In grass species, the regrowth period can also be influenced by harvesting or grazing, especially as a function of SH, which is directly related to the remaining LAR. Pastures managed under lower SH need longer intervals to recover leaf area to be able to achieve 95% LI. As a consequence, they show a longer regrowth period, which, in practice, is not recommended. The management of Tanzania grass in an intermittent grazing system has been recommended in Brazil with a pre-grazing height of 70 cm (LI = 95%) (Euclides et al. 2014; Zanine et al. 2018) and a post-grazing SH close to 50% of the pre-grazing height, i.e. 35 cm. However, what differs in the studies are the varying regrowth periods required by the grass to start from SH of 35 cm and reach 95% LI (70 cm). These differences in regrowth period are usually related to factors such as time of year, soil management and fertility and the climate of the region, warranting the development of studies in different parts of the country. On average, the regrowth period of Tanzania grass in the RS in central Brazil has ranged between 21 and 32 days, at pre- and post-grazing heights of 70 and 35 cm, respectively. In our study, this regrowth period was 41.2 days, as the grass reached 95% LI at the greatest average height (76.5 cm). This was probably due to the typical excess rainfall that occurs in the region during the RS (2,086 mm in 2018), leaving part of the months with a cloudy sky.

Morphogenetic and structural traits

Decreasing LAR in tropical grasses in response to increases in SH (Table 4) are usually associated with the longer pseudostems that occur at greater stubble heights, which, in turn, result in a greater distance to be traveled by the leaf until its exposure above the tube (Lemaire and Chapman 1996). This is better understood when we analyze the increase in PHY, i.e. the time taken for two consecutive leaves in the tiller to appear, following an increase in SH. Phyllochron follows an inverse response pattern to that of LAR; at lower SH, PHY tends to decrease and LAR tends to increase, possibly related to the plant's need to restore the photosynthetic apparatus shortly after harvest or a more intense grazing event. Similar results showing a decrease in LAR and an increase in PHY following increases in SH were described by Silva et al. (2016) in Tifton-85 pastures, reinforcing the inverse relationship between these variables.

Higher LER occurs at higher SH (Table 4), due to the elongation of pseudostems. Shorter pseudostems favor a rapid leaf emergence, resulting in lower LER. The opposite is also true, as leaves take longer to emerge from longer pseudostems, resulting in higher LER. In this respect, Zanine et al. (2018) observed an increase in LER from 11.54 to 15.21 cm/tiller/d as SH was increased from 30 to 50 cm in Tanzania grass pastures managed at 95% LI in the pre-grazing condition during the RS. The higher LER (3.43 cm/tiller/d) seen in the RS was likely due to the greater water availability during this season than in the DS (2,087 vs. 169 mm). Barbosa et al. (2011) studied the effects of defoliation intensities and frequencies in Tanzania grass and observed LER of 4.16 and 1.16 cm/tiller/d in the rainy and dry seasons, respectively, and associated this difference with climatic differences between the two seasons.

The increase in LSR in response to increasing SH observed in both seasons (Table 4) is related to intraspecific competition for light, which reduces the quantity and quality of the light that penetrates the pasture as the grass becomes taller. As an adaptation response to this competition, the plant starts to invest in elongating its internodes to elevate leaves to the top of the pasture, where light is more abundant. Simultaneously, the leaves located at the base of the tussocks become more shaded, which accelerates leaf senescence (Duchini et al. 2013). For this reason, during the regrowth period, both SER and LSR exhibit the same response pattern. These results corroborate those described by Silva et al. (2016) in Tifton-85 grass.

Leaf lifespan expresses the tissue flow occurring in the plant, which is normally higher during the DS (Table 4). The longer LLS in the DS may be the result of low precipitation as well as lower day-length, which are typical of this season in tropical conditions. In this scenario, grasses extend the lifespan of green leaves and reduce leaf tissue turnover, which results in lower LAR and LER as well as a longer PHY, as previously discussed. It is thus clear that these traits are influenced by seasons of the year, which are directly related to environmental conditions.

The shortened LLS in response to increasing SH in both seasons (Table 4) can be better understood when considered together with the leaf senescence process, which increased along with increasing SH. Once senescence is established, nutrients are redirected to younger leaves, which reduces the photosynthetic activity of older leaves and leads to a reduction in LLS (Oliveira et al. 2007), as observed in our study.

From SH of 35 cm upwards, higher SER was observed during the RS (Table 4), which may be associated with a larger amount of leaves remaining after harvest at these greater SHs. These remaining leaves usually cause shading on the tillers, prompting them to elongate their stem to capture light in the upper layers of the canopy, which also explains the linear increase in SER along with increasing SH. Another explanation for the difference in SER between the seasons may be related to the reproductive stage of the cultivar, which produces inflorescences during the summer (RS) under tropical conditions. As inflorescence-emergence approaches, tropical grasses elongate their stems so that the inflorescences reach and remain in the upper strata of the pasture (Pedreira et al. 2017), in an attempt to facilitate seed dispersal. Zanine et al. (2018), working with the same guinea grass (cv. Tanzania) also observed a higher mean SER in summer than in winter (13.38 vs. 4.87 mm/tiller/d) and in pastures under greater SH (50 vs. 30 cm) during summer (15.21 vs. 11.54 mm/tiller/d).

Leaf blade length, represented by FLS, is a structural variable that responds to the intensity of defoliation. Higher values for this variable are associated with greater SH, agreeing with the greater leaf sheath length (Volaire et al. 2014). Thus, the distance to be traveled by the leaf blade inside the pseudostem is greater, which results in an extended elongation time and, consequently, a longer new leaf (Duru and Ducrocq 2000). However, this response pattern was observed only during the DS, which still provided the lowest FLS as compared with the RS for stubble heights up to 45 cm (Table 5). This reduction in FLS during the DS may be associated with the lower average LER observed in this season (Table 4), as these two traits are known to be correlated (Lemaire and Chapman 1996).

Since it is inversely related to LSR, the number of live leaves per tiller decreased in both seasons with increase in SH (Table 5), whereas average LSR increased (Table 4). This is likely because, as they contained larger proportions of senescent leaves at the base of the canopy, pastures with greater SH had a higher percentage of dead leaves, which resulted in a lower NLL per tiller, as well as the greater SH displaying lower LAR (Table 4). These effects were also described by De Carvalho et al. (2016) and Silva et al. (2016) in Tifton-85 grass managed under different grazing intensities.

Stubble height is a factor that affects tiller density, with higher densities being commonly observed in shorter pastures (lower SH) and vice-versa (Lima et al. 2017; Santana et al. 2017). This fact can be explained as a response to the tiller size/density compensation mechanism existing in higher plant communities (Matthew et al. 1995). By using this mechanism, grasses regulate pasture leaf area and, consequently, the ability to intercept incoming light. This can cause greater shading at the base of the canopy under higher LAI, which can reduce the stimulation of the basal and axillary buds for the production of new tillers. Indeed, LAI rose linearly with increasing SH, which reinforces the premise described. This increase in LAI may be associated with the increase in LER as SH was raised.

When managed under lower SH, Tanzania grass may exhibit a higher TMR (Table 6), which is likely due to the removal of the apical meristem at harvest, as it is considered a tall grass, reaching 1.2 m in height in free growth. On the other hand, lower SH also promotes higher TAR, which indicates that there was a balance between deaths and the appearance of tillers at the lower SH, which contributed to the perenniality of the cultivar. The inverse relationship between SH and TAR observed in the study can be explained by the greater light intensity that reaches the base of the canopies managed under lower SH, in addition to the higher LAR (Sbrissia et al. 2010) (Table 4). In theory, the appearance of a new leaf allows the development of a new tiller (Skinner and Nelson 1992).

Knowledge about seasonal variations in the rates of tiller appearance, mortality and, consequently, survival, is important for understanding the mechanisms involved in perenniality and tiller turnover in pastures. During the RS, although the pastures had a higher TAR (42.9 tillers/100 tillers), it was not high enough to compensate for lower tiller survival (60.29 tillers/100 tillers) than in the DS (67.53 tillers/100 tillers), and this condition could negatively affect plant persistence and pasture productivity. On the other hand, during the DS, despite the low rate of tiller appearance, their survival was high, in an effort to maintain pasture persistence under these climatic conditions.

Herbage accumulation and morphological composition

With increase in SH the plants needed a shorter time interval and, probably, smaller amounts of reserves to reach 95% LI, i.e. a shorter regrowth period (Silva et al. 2019). This led to a decrease in THA as compared with the pastures with lower SH, which required a longer interval to intercept 95% of incident light again and thus accumulated more herbage. Other evaluated factors that also help to explain the decreasing THA in response to the increase in SH were the reductions in leaf and tiller appearance rates and tiller density as well as increasing leaf senescence, as SH was increased. Similarly, Hamilton et al. (2013) reported a reduction in the accumulation of ryegrass and tall-fescue herbage when SH was increased from 2 to 15 cm.

Only about 22% of THA occurred in the DS, which would be due to climatic conditions being favorable for regrowth of the grass in the RS (higher precipitation rates, mainly), favoring greater number of harvests in that period, which is consistent with the premise that tropical pastures in Brazil produce 60–80% of the total herbage mass in the RS and the remaining 20–40% in the DS (Pedreira et al. 2005; Fernandes et al. 2014; Oliveira et al. 2020). This more favorable environment reduced the average regrowth period from 80.1 days in the DS to 51.2 days in the RS, resulting in more harvests being possible during the RS. In addition, variables directly related to herbage accumulation, such as LAR, LER and SER, were higher in the RS. Our findings confirm the existence of production seasonality in grasses of the genus *Megathyrsus*, corroborating the results reported by Luna et al. (2016) and Santos et al. (2016). One must also remember that the RS was twice as long as the DS.

The proportion of leaf blade (LB) in herbage accumulated above the stubble increased with increasing SH in both seasons, whereas the average proportion of ST decreased (Table 7). When we increased SH, we harvested the herbage in the upper strata of the canopy, where there is a higher proportion of leaves and a lower percentage of stems. In practice, to maximize herbage accumulation, Tanzania grass pastures must be managed at lower SH. However, this accumulated herbage contains a lower proportion of green leaves and a higher proportion of stems than forage from a greater SH, where there is less THA with a higher proportion of green leaves and a lower proportion of stems. Therefore, in ideal terms, a compromise should be made in choosing the SH to balance the amount of accumulated herbage with its nutritional value.

The higher proportion of LB observed at the SH of 15 cm during the DS (Table 7) may be due to the greater removal of morphological components, which put the plants in an even more adverse condition than is ‘normal’ in the DS. Thus, the plants needed to rebuild their leaf area and maintain more leaves alive (NLL) to ensure the perenniality of the cultivar. The higher proportion of LB in the herbage accumulated at SH of 55 cm during the RS may be related mainly to the effect of herbage harvest in the upper stratum, as highlighted above, as well as the greater precipitation occurring during this season.

Long regrowth periods, resulting from low SH, culminated in undesirable changes in the structure of the forage canopy, characterized by an increased proportion of ST and DeM in the herbage accumulated above the stubble. Under grazing conditions this can result in herbage losses due to the amount of material largely rejected by grazing animals, thereby negatively influencing harvest efficiency and the nutritional value of the produced material.

The observed decrease in the proportion of ST in the accumulated herbage with increasing SH was due to the harvest intensities themselves. In tropical pastures, it is known that, from a certain point (strata closer to the ground level), the stem component starts to represent a much more significant percentage of the stratum. This can affect herbage intake, since intake can be affected by components associated with the architecture and the morphological and botanical composition of the pasture, which define its structure. Stem is the component that most restricts intake due to the physical barrier it imposes on the grazing process (Laca and Lemaire 2000). Fontes et al. (2014) examined the effect of defoliation intensities in *Brachiaria* grasses and also observed that higher defoliation intensities resulted in a higher proportion of stems in the samples.

This study made it possible to confirm the hypothesis that interactions between seasons of the year in the eastern Amazon region and SH affect the structure and production of Tanzania grass. In the DS, Tanzania grass changed its morphogenetic and structural traits to result in only 22.6% of annual total herbage accumulation occurring during the DS. The remaining 77% of herbage accumulation was due to the beneficial changes in the morphogenetic and structural traits of the grass provided by the favorable climatic conditions occurring in the RS. Results from this study lead us to conclude that Tanzania grass should be managed at SH between 35 and 45 cm in the DS, corresponding to RP from 61 to 64 days, and at SH of 35 cm in the RS, corresponding to RP of 41 days. This should result in a compromise between yield and quality of forage produced. Studies to assess the outcome of such a strategy seem warranted.

Acknowledgments

To Coordenação de Aperfeiçoamento de Pessoa de Nível Superior (CAPES) for the first author's scholarship.

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(Note of the editors: All hyperlinks were verified 9 July 2021).

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(Received for publication 31 July 2020; accepted 24 June 2021; published 30 September 2021)