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Intermittent stocking strategies for the management of Marandu palisade grass in the Brazilian Cerrado biome

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Abstract

The objective of the study was to evaluate the effect of pre- and post-grazing targets on the forage accumulation and canopy characteristics of Marandu palisade grass (*Brachiaria brizantha* [Hochst. ex A. Rich.] Stapf. syn. *Urochloa brizantha*) to define grazing management strategies in Brazil's Cerrado biome. The experimental design comprised a randomized complete block with four replicates in a 2 × 2 factorial arrangement of treatments: two grazing frequencies (95% of light interception (LI95%) and maximum (LIMax) light interception of the forage canopy) and two grazing intensities (10 and 15 cm of post-grazing canopy height). Pastures were sampled to quantify forage mass and morphological components at pre- and post-grazing. The tillers population density and forage nutritive value were estimated at pre-grazing. Pastures managed with the LI95% target demonstrated greater basal (1,341 versus 1,193 tillers/m^2) and aerial tillers (101 versus 53 tillers/m^2) population densities, a greater leaf:stem ratio (3.8 versus 2.0), and a lower canopy height (33 versus 55 cm), forage mass (3,225 versus 4,320 kg/ha), stem proportion (30.6% versus 44.5%), and leaf (2.5% versus 2.8%) and stem (3.4% versus 3.8%) acid detergent lignin content than those managed with the LIMax target. In the Cerrado, Marandu palisade grass must be grazed when the canopy height reaches 33 cm. Furthermore, animals must be removed from the paddocks when the canopy height reaches 15 cm.

KEYWORDS
canopy height, light interception, nutritive value, tillers population density

1 | INTRODUCTION

Brazil has 160 million hectares of pastures, supporting a bovine herd of 172 million (Brazilian Institute of Geography and Statistics, 2017). Approximately, half of the beef cattle and planted pastures in Brazil are located in the Cerrado region, where the soil is deficient in nutrients such as calcium, magnesium and especially phosphorus; highly oxidized; rich in iron and aluminum; and prone to weathering and degradation (Martha Júnior et al., 2007). In this context, *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf. cv. Marandu has gained popularity due to its ability to adapt to edaphic conditions and respond to intensification in different production systems (Euclides et al., 2019). However, inadequate grazing management may lead to inefficient use of the forage produced and even pasture degradation (Sone et al., 2020), regardless of the cultivars involved.

Studies evaluating the impact of management strategies on canopy structure, as well as plant and animal response, are essential in determining effective grazing practices (Hodgson, 1985). Giacomini et al. (2009) evaluated Marandu palisade grass pastures grown in a highly fertile soil (eutroferric red nitosol) fertilized with 190 kg N/ha/year, submitted to two rest periods based on pre-grazing canopy targets of 95 or 100 light interception (LI) and 10 and 15 cm post-grazing heights (RH). They reported (a) stem elongation and foliar senescence processes occurred at over LI95%, indicating that the regrowth process should ideally be interrupted when such a LI level is reached; (b) pastures grazed to 15 cm produced greater forage accumulation and grazing efficiency.

Studies with tropical grasses (Anjos et al., 2016; Pedreira et al., 2017; Alvarenga et al., 2020) suggest that canopy height may be a reliable criterion for determining when to reintroduce animals in pastures managed under intermittent stocking. Thus, production systems have been applied grazing management strategies based on existing recommendations of canopy height targets for tropical grasses like *Panicum maximum* Jacq. cvs. Mombaça and Tanzânia, *Brachiaria brizantha* cvs. Xaraés.

Pontes et al. (2016) found that the same warm-season grass generated different canopy heights when submitted to contrasting nitrogen levels (namely, 0 kg/ha and 300 kg/ha) and that soil conditions could affect canopy characteristics and the height at which LI95% occurs.

Within this theoretical framework, the present study aims to provide reliable information regarding pre- and post-grazing canopy height targets for Marandu palisade grass in the Cerrado biome. It was hypothesized that the Marandu palisade grass pasture established in the Cerrado biome will exhibit a different canopy structure than one established in a eutroferric red nitosol (Giacomini et al., 2009). In particular, low soil fertility in Brazil's Cerrado could lead to a reduction in the tillers density and, consequently, the production of forage in comparison with eutroferric red soil (higher fertility) at the same LI level. The objective of the study was to evaluate the effect of pre- and post-grazing targets on the forage accumulation and canopy characteristics of Marandu palisade grass (*Brachiaria brizantha* [Hochst. ex A. Rich.] Stapf. syn. *Urochloa brizantha*) to define grazing management strategies in Brazil's Cerrado biome.

2 | MATERIALS AND METHODS

The experiment was carried out at Embrapa Beef Cattle, Campo Grande, MS (20°27'S and 54°37'W, 530 m above sea level) for a total of 547 days between November 2012 and May 2014. According to the Köppen classification, the climate in the region lies between zones Cfa (humid subtropical) and Aw (tropical wet and dry). Meteorological data were collected at Embrapa Beef Cattle weather station (Figure 1), at a distance of 3 km from the experimental area.

The soil in the region has been classified as a dystrophic red latosol (FAO, 2006). Average soil chemical characteristics before pasture establishment were as follows: pH ($CaCl_2$) = 5.34; Ca = 3.28 $cmol_c/dm^3$; Mg = 1.41 $cmol_c/dm^3$; Ca + Mg = 4.69 $cmol_c/dm^3$; Al = 0.03 $cmol_c/dm^3$; H + Al = 4.37 $cmol_c dm^3$; sum of bases = 4.97 $cmol_c/dm^3$; base saturation = 53.1%; organic matter = 3.5%; P Mehlich-1 = 7.8 mg/dm^3; K Mehlich-1 = 109 mg/dm^3. The soil was fertilized with 39 kg/ha P; 75 kg/ha K before palisade grass pastures were established in January 2012. No-till farming was used to sow 5 kg/ha of pure and viable seeds, with 30 cm spacing between rows. In April 2012, pastures were grazed to stimulate tillering, and in May 2012, fences were built and drinking troughs were installed. On November 6, 2012, pastures were mowed to a height of 15 cm in all paddocks to ensure canopy uniformity, using a manual mower. After that, the paddocks were submitted to a rest period until reach the pre-grazing targets according to experimental treatments. The post-grazing conditions of 10 and 15 cm were generated by grazing animals. The grazing was starting on November 27, 2012.

The experimental design comprised a randomized complete block with four replicates and a 2x2 factorial arrangement of treatments: two grazing frequencies (95% of light interception (LI95%) and maximum light interception (LIMax) of the forage canopy) and

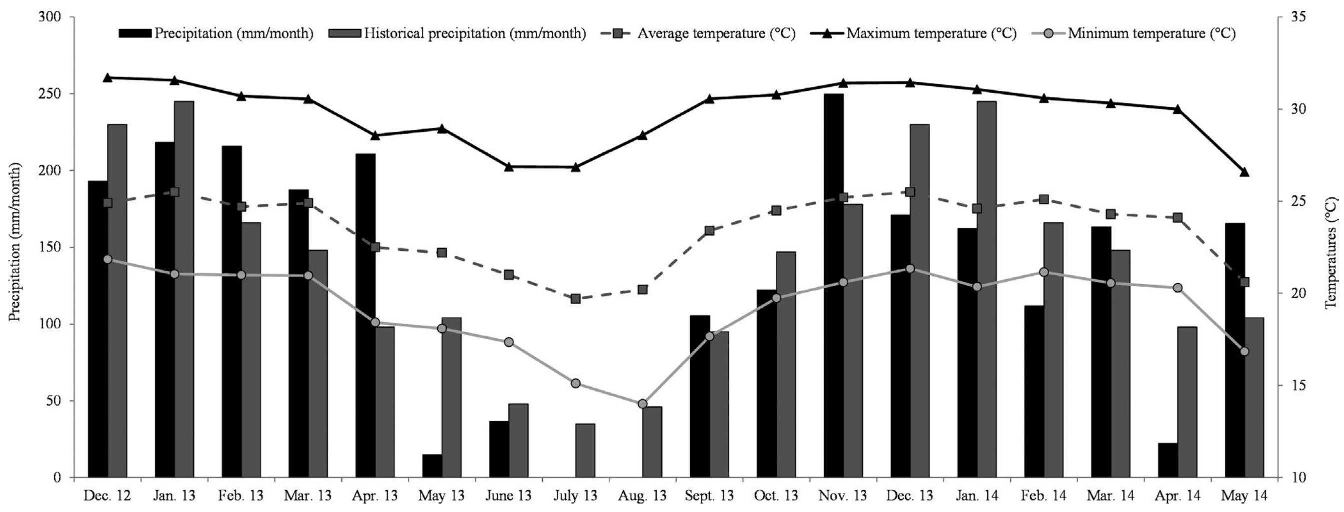

FIGURE 1 Mean, minimum and maximum temperatures and monthly precipitation during the experimental period

two grazing intensities (10 and 15 cm of post-grazing canopy height). The area was split into four blocks of 0.2 ha each, with each block containing four paddocks of 0.05 ha divided by electric fences.

The soil was fertilized with 150 kg N/ha/year during the rainy season, exclusively post-grazing. The N fertilization split-applied in the three applications, using two nitrogen sources: in the first annual application (December 2012 and November 2013), ammonium sulfate was used; in the next two annual applications (January 2013 and 2014, March 2013 and 2014), urea was used.

The intermittent stocking was used with variable stocking rate. Grazing intervals corresponded to the period of time required for the forage canopy intercept 95% of the incident radiation or the maximum interception of light, depending on the treatment, and occupation periods corresponded to the period of time needed for post-grazing waste to be reached according to treatment, which was 10 or 15 cm in height. The lowering of pastures was carried out by male crossbreed cattle, with an average live weight of 250 kg. The animals were led to the paddocks when the canopy reached the condition recommended pre-grazing and were removed when the desired waste height was reached. The number of animals in each paddock was determined according to the post-grazing height target, keeping an occupation period of fewer than 7 days.

The light interception (LI) was measured with an AccuPAR Linear PAR/LAI ceptometer, model PAR-80 (DECAGON Devices), following the manufacturer's instructions. Readings, one at the top of the canopy and another at soil level, were carried out at 20 locations per paddock. During the rest period, readings were carried out once a week. When LI levels were close to pre-grazing targets, monitoring frequency increased and readings were carried out every other day until the targets were reached. The LIMax occurred when the LI was almost complete that was set at 97.5% or more in two consecutive twice a week measurements.

Canopy height was determined using a ruler at 20 random locations per paddock. The height at each location was measured as the mean canopy height around the ruler. It was read in the pre-grazing when the paddocks reached target LI levels, and in the post-grazing, immediately after the animals left the paddocks.

Tiller population density was determined by counting basal and aerial tillers at three sites per paddock with mean pasture condition scores. The count was performed before grazing in each cycle, using a metal rectangle (1 m × 0.25 m).

The forage mass (FM) was estimated in the pre- and post-grazing by randomly cutting four samples of forage (1 m^2 per sample) in each paddock at the soil level. In order to assess FM, each sample was split into two parts. One part was stored in a paper bag and dried in a forced-air oven at 55°C until a constant weight was achieved. The other was manually separated into leaf (leaf blade), stem (stem and sheath), dead material and components were dried in a forced-air oven at 55°C until a constant weight was achieved; they were then weighed.

The forage accumulation rate (FAR) was calculated as the difference between the current pre-grazing FM and the previous post-grazing FM of only the green portion of the grass (leaf and stem), divided by the number of days between samplings. The leaf-blade accumulation rate (LAR) was similarly estimated, using leaf proportion (LP) values at the pre- and post-grazing conditions.

Forage nutritive value was measured at pre-grazing leaf and stem fractions. The curves were calibrated in a FOSS NIRSystems Model 5,000, using ISI WINISI II Project Manager V1.02 software. The curves of scalibration are carried out by 100–150 wet analyses of forage per year, since 1997. The crude protein (CP) standard error of calibration (SEC), standard error of prediction (SEP), R^2 of calibration (RCAL) and R^2 of prediction (RPRE) were 1.51, 1.48, 0.85 and 0.84, respectively. For neutral detergent fiber of organic matter (NDFom), the SEC was 8.74, the SEP 8.12, the RCAL 0.67 and the RPRE 0.70. For ADL, the SEC was 0.51, the SEP 0.69, the RCAL 0.91 and the RPRE 0.86. For in vitro digestibility of organic matter (IVDOM), the SEP was 4.09, the SEC 4.11, the RCAL 0.87 and the RPRE 0.88.

Data were grouped according to the season as follows: summer (December 21, 2012, to March 20, 2013 and December 21, 2013, to March 20, 2014), fall (March 21 to June 20, 2013 and March 21 to May 28, 2014), winter (June 21 to September 20, 2013) and spring (September 21 to December 20, 2013). The response variables were analyzed by fitting mixed-effects models using the MIXED procedure in SAS (Statistical Analysis System, version 9.4). The Akaike information criterion was used to select the covariance matrix (Wolfinger, 1993). The applied model included the random effect of the blocks, the fixed effects of LI, post-grazing heights, the season and the interactions of these factors. Averages of the treatments were compared using the Tukey test ($p < .05$).

3 | RESULTS

The average LI for LI95% was 95.2% (*SEM* = 0.5%), while for LIMax was 98.3% (*SEM* = 0.7%). The correlation between pre-grazing LI and canopy height was significant ($p = .0001$; $r = 0.84$). The post-grazing height of 15 cm was reached regardless of the pre-grazing LI target, with a mean of 15.6 cm (*SEM* = 0.6 cm). However, achieving a post-grazing height of 10 cm was difficult at the LI95% pre-grazing target (mean = 11.5 cm; *SEM* = 1.1 cm) and even more so at the LIMax target (mean = 14.2 cm; *SEM* = 1.6 cm).

The significance levels of the fixed effects and their interactions for all response variables are presented in Table 1. The interaction between LI and the seasons was observed for the rest period, FAR, LAR and in the pre-grazing condition (Tables 1 and 2). Pastures managed with LI95% had a longer resting period in spring and winter, shorter during summer and intermediate in fall. When managed with LIMax, pastures also had the longest rest periods in spring and winter and the shortest in fall and summer. Longer rest periods were observed for pastures managed with LIMax in all seasons except fall when LI95% and LIMax were similar (Table 2).

The FAR and LAR were greater in summer, fall and spring and lower in winter when pastures were subjected to LI95% or LIMax. Moreover, the FAR and LAR were greater when pastures were

TABLE 1 Significance levels (*p*-value) for the effect of light interception (LI), post-grazing height (RH), season (Sea) and its interactions under the response variables

Parameters	LI	RH	Sea	LI*RH	LI*Sea	RH*Sea	LI*RH*Sea
Rest period (RP)	<0.001	0.743	<0.001	0.767	0.004	0.940	0.081
Forage accumulation rate (FAR)	0.007	0.116	<0.001	0.818	0.018	0.752	0.737
Leaf-blade accumulation rate (LAR)	<0.001	0.096	<0.001	0.774	0.003	0.654	0.480
Basal tiller population density (BPTD)	0.007	0.653	<0.001	0.869	0.285	0.903	0.362
Aerial tiller population density (ATPD)	0.002	0.756	0.120	0.191	0.143	0.860	0.804
Pre-grazing							
Canopy height (CH)	0.001	0.947	0.130	0.629	0.059	0.936	0.688
Forage mass (FM)	<0.001	0.051	0.297	0.278	0.073	0.266	0.299
Leaf-blade proportion (LP)	<0.001	0.029	<0.001	0.532	0.001	0.088	0.237
Stem proportion (SP)	<0.001	0.852	0.072	0.358	0.211	0.244	0.501
Dead material proportion (DP)	0.016	0.009	0.047	0.105	0.090	0.113	0.452
Leaf:stem ratio (LSR)	<0.001	0.192	<0.001	0.724	0.109	0.296	0.603
Leaf crude protein (CP)	0.040	0.158	0.171	0.661	0.113	0.710	0.974
Leaf in vitro digestibility of organic matter (IVDOM)	0.120	0.222	0.608	0.498	0.401	0.154	0.211
Leaf neutral detergent fiber (NDFom)	0.041	0.756	0.071	0.522	0.423	0.749	0.473
Leaf acid detergent lignin (ADL)	0.001	0.734	0.853	0.355	0.351	0.845	0.785
Stem crude protein (CP)	0.871	0.904	0.340	0.922	0.268	0.920	0.749
Stem in vitro digestibility of organic matter (IVDOM)	0.673	0.809	0.542	0.839	0.162	0.525	0.479
Stem neutral detergent fiber (NDFom)	0.249	0.573	0.058	0.774	0.088	0.423	0.136
Stem acid detergent lignin (ADL)	<0.001	0.885	0.771	0.638	0.211	0.360	0.256
Post-grazing							
Forage mass (FM)	<0.001	0.249	0.408	0.484	0.136	0.705	0.693
Leaf proportion (LP)	<0.001	0.234	0.007	0.483	0.452	0.231	0.576
Stem proportion (SP)	0.002	0.957	0.140	0.664	0.104	0.727	0.997
Dead material proportion (DP)	0.273	0.537	0.080	0.954	0.071	0.457	0.836

managed with LI95% for all seasons except winter when no differences between LI95% and LIMax were observed (Table 2).

The LP was greater in spring and summer, intermediate in fall and lower in winter in LI95% pastures. When managed with LIMax, pastures demonstrated the highest LP in spring, followed by fall and summer, and the lowest LP in winter. Pastures managed with LI95% demonstrated the highest LP in all seasons except fall (Table 2).

The LI effect was observed for the basilar and aerial tiller population densities (BTPD and ATPD), canopy height, FM, leaf:stem ratio (LSR), stem proportion (SP), dead material proportion (DP), CP in leaves, neutral detergent fiber (NDFom) in leaves and, ADL in leaves and stems in the pre-grazing condition (Table 3). In the post-grazing condition, the LI effect influenced the values of FM, LP and SP (Table 3). When pastures were managed with LI95%, a greater BTPD, ATPD and LSR were observed. A lesser canopy height, FM, SP and ADL of leaves and stems were also observed in the pre-grazing for LI95% condition in comparison with pastures managed with LIMax. In post-grazing, a greater LP and lesser FM and SP were observed in LI95% pastures compared with LIMax ones. No LI effects were observed for the other variables evaluated (Table 1).

No interaction effect of LI and RH occurred for any variable response (Table 1). The RH effect was observed only for the LP and DP. Pastures lowered at 15 cm had the highest LP and lowest DP (Table 4).

The season effect was observed for the BTPD, DP and LSR in pre-grazing: The BTPD was greater during summer and fall and lesser in spring and winter. The DP was greater in winter, intermediate in summer and fall and lesser in spring, while the LSR was greater in spring and summer and lesser in fall and winter (Table 5). In post-grazing, the season effect was also observed for the LP, which was greater in spring, intermediate in summer and fall and lesser in winter (Table 5). No season effects were observed for the other variables evaluated (Table 1).

4 | DISCUSSION

The 15 cm post-grazing condition was achieved in LI95% and LIMax pastures, the grazing animals struggled to lower pastures when the exit target was 10 cm. When the entry condition was LI95%, the exit height was averagely 1.1 cm above the target. Nevertheless, when

TABLE 2 Mean and standard error of the mean for rest period, forage and leaf-blade accumulation rates (FAR and LAR) and leaf-blade proportion (LP) according to light interception*season effect

Parameters	Season: Spring	Summer	Fall	Winter
Rest period (days)				
LI95%	88.7Ba ± 3.4	33.1Bc ± 1.1	69.5Ab ± 2.4	89.8Ba ± 3.8
LIMax	115.0Aa ± 3.8	56.4Ab ± 2.1	60.3Ab ± 3.5	112.2Aa ± 4.3
Forage accumulation rate (FAR: kg/ha/day)				
LI95%	34.8Ac ± 4.2	82.3Aa ± 2.8	58.4Ab ± 3.8	18.6Ad ± 4.6
LIMax	21.6Bc ± 4.8	61.2Ba ± 3.7	38.1Bb ±4.7	25.8Abc ± 4.9
Leaf-blade accumulation rate (LAR: kg/ha/day)				
LI95%	26.9Ac ± 3.8	61.4Aa ± 2.4	40.6Ab ± 2.8	15.5Ad ± 4.3
LIMax	15.8Bc ± 4.4	37.8Ba ± 3.5	23.8Bb ± 4.2	12.0Ac ± 4.9
Leaf-blade proportion (LP: %)				
LI95%	77.9Aa ± 1.2	74.3Aa ± 0.9	69.6Aab ± 1.3	63.9Ab ± 1.6
LIMax	67.9Ba ± 1.7	60.9Bb ± 1.2	62.4Aab ± 1.7	53.5Bc ± 2.1

Note: Means followed by the same capital letter in the columns and same lowercase letter in the row are not different according to Tukey's test at 5% probability.

TABLE 3 Means and standard error of the mean (*SEM*) of the productive, structural and nutritive characteristics on pre- and post-grazing condition in *Brachiaria brizantha* cv. Marandu pasture under two frequencies (LI95% and LIMax) of intermittent stocking management

	Light interception (LI)			
	LI95%		LIMax	
Parameters	Mean	*SEM*	Mean	*SEM*
Pre-grazing				
Basal tiller (tillers/m^2)	1,341	18	1,193	22
Aerial tiller (tillers/m^2)	101	9.4	53	11.3
Canopy height (cm)	33.0	1.0	55.0	0.8
Forage mass (kg DM/ha)	3,225	65	4,320	78
Stem (%)	30.6	2.0	44.5	1.6
Dead material (%)	8.2	0.6	10.7	0.7
Leaf:stem ratio	3.8	0.1	2.0	0.1
CP in leaf (%)	12.7	0.2	11.3	0.3
NDFom in leaf (%)	70.4	0.2	72.7	0.3
ADL in leaf (%)	2.5	0.05	2.8	0.07
ADL in stem (%)	3.4	0.06	3.8	0.08
Post-grazing				
Forage mass (FM: kg DM/ha)	1,667	55	2,066	66
Leaf (%)	15.5	1.0	10.2	1.2
Stem (%)	29.8	1.4	38.3	1.7

Abbreviations: ADL, Acid detergent lignin; CP, crude protein; DM, dry matter; NDFom, neutral detergent fiber.

less frequent grazing (LIMax) was adopted, the greater pre-grazing height, FM and presence of stems (Table 2) made it difficult for the animals to lower pastures to a height of 10 cm (Carnevalli et al., 2006), functioning as a barrier to grazing.

TABLE 4 Means and standard error of the mean (*SEM*) for leaf and dead material proportions from pastures of *Brachiaria brizantha* cv. Marandu under intermittent stocking management and two post-grazing heights

	Post-grazing height (cm)			
	10		15	
Parameter	Mean	*SEM*	Mean	*SEM*
Leaf (%)	64.4	0.8	66.8	0.9
Dead material (%)	10.7	0.7	8.2	0.7

Real canopy heights at post-grazing were close for pastures managed with both treatments (10 and 15 cm); however, primarily for LIMax-managed pastures, differences in the morphological composition of the stubble (post-grazing condition) were observed in the LP and DP (Table 4). When pastures were grazed to 10 rather than 15 cm, fewer leaves remained in the stubble due to the size of the remaining tillers, and the DP was 10 cm greater (Table 4). Giacomini et al. (2009) and Echeverria et al. (2016) also reported greater stem elongation in pastures with *Brachiaria* cultivars managed with pre-grazing targets over LI95%. These authors reported difficulties with reaching the post-grazing conditions, predominantly in ILMax-managed pastures submitted to high grazing intensity (10 cm). Since grazing animals prefer to consume leaves, the presence of stems in the grazing horizon hinders intake (Mezzalira et al., 2014), as the post-grazing height of LIMax-managed pastures indicates (Table 4).

The pre-grazing heights for LI95% (33 cm) and LIMax (55 cm) pastures were consistent throughout the experimental period and independent of the physiological condition of the pastures (i.e., vegetative or reproductive; Table 3). The correlation (0.84) between the pre-grazing heights and LI suggests that controlling forage canopy conditions using height can help manage tropical

TABLE 5 Means and standard error of the mean (*SEM*) of the basal tillers (tiller/m^2), dead material proportion (%), and leaf:stem ratio in the pre-grazing, and leaf proportion (%) in the post-grazing from pastures of *Brachiaria brizantha* cv. Marandu under two grazing frequencies and two grazing intensities as a function of seasons

Parameters	Spring	Summer	Fall	Winter	*SEM*
Pre-grazing					
Basal tiller density (tiller/m^2)	1,190b	1,379a	1,279ab	1,176b	65.2
Dead material (%)	5.1c	6.7b	7.7b	16.1a	1.1
Leaf:stem ratio	2.9a	3.0a	2.6b	2.4b	0.2
Post-grazing					
Leaf (%)	78.8a	67.1b	63.3b	59.6c	1.1

Note: Means followed by the same lowercase letter in the row are not different according to Tukey's test at 5% probability.

grasses (Anjos et al., 2016; Pedreira et al., 2017; Alvarenga et al., 2020). However, the mean pasture height in this study (33 cm) was greater than Giacomini et al. (2009), who observed 25 cm of height for IL95%. The differences in soil fertility can promote differences in the mean heights of the LIMax-managed pastures. In the case of Giacomini et al. (2009), pastures were planted in a eutroferric red nitosol (FAO, 2006) resulting in the average FM was 7,100 kg/ha dry matter (DM) with LI95% and 8,260 kg/ha DM with LIMax. However, as the current study was conducted in a dystrophic red latosol (FAO, 2006), and the corresponding FM values were 3,230 kg/ha DM and 4,280 kg/ha DM. Probably, the forage density obtained by Giacomini et al. (2009) was great, which likely lead the plant to reach the critical leaf area index at a lower canopy height.

Monitoring the growth of pastures based on the light interception of the canopy can be considered an alternative to using consolidated management for tropical grasses managed under intermittent stocking (Carnevalli et al., 2006; Silva et al., 2009; Echeverria et al., 2016; Alvarenga et al., 2020). Interrupting the pastures' regrowth process based on the LI allows the tropical forages to reach the maximum net forage accumulation (Pedreira et al., 2017), controlling the accumulation of stems and dead material from modifying the canopy structure (Silva et al., 2009).

When pastures were managed with LI95% in the pre-grazing condition, they could reach additional grazing cycles during the growing season (Echeverria et al., 2016). Indeed, four additional grazing cycles were observed for pastures managed with LI95% compared with LIMax. Shorter rest periods observed throughout the seasons promoted an increase in the number of grazing cycles (Table 2) of pastures managed with LI95% compared with LIMax (LI*SEA interaction effect). The regrowth duration depends on the FAR in each season (Table 2), which, in turn, influences the LAR (Table 2). Although the forage growth (FAR and LAR) was similar in winter (Table 2) for both LI treatments, the rest period was 22.4 days shorter for pastures managed with LI95% compared with LIMax. While the grazing period depended on the regrowth speed of each paddock, based on FAR and LAR (Table 2) variations, 5–6 days in spring-summer and 7–9 days in fall-winter were averagely used. The rest period observed was longer than that was observed by Giacomini et al. (2009) in the Marandu palisade grass pastures sown in an eutroferric red nitosol. The authors discerned 28.7 days in the growing season (October to February) and 45.7 days from March to September, while Anjos et al. (2016) discerned 22.8 days in the growing season (October to May) for Marandu palisade grass managed with LI95% in a distrophic fluvisol.

The regrowth rate of pastures after defoliation depends on the edaphoclimatic factors present at a given moment. Fluctuations in weather conditions, which result in thermal and water stress, can affect canopy characteristics and thus limit production and the forage nutritive value (Buxton & Fales, 1994). The seasonal variation in the FAR and LAR (Table 2) is common in tropical regions and results mainly from rainfall distribution (Figure 1). It is important to note that even with seasonal variations in the FAR and LAR, pastures managed with LI95% presented more forage accumulation than those managed with LIMax (Table 2). Giacomini et al. (2009) and Echeverria et al. (2016) obtained similar results.

Respecting the moment when the canopy reaches a critical leaf area index (95%LI), when a pasture has the greatest FAR (Brougham, 1955, 1956) and LAR, is a way to control forage nutritive value, based on the lesser levels of ADL in leaves and stems (Table 3). In the LI95%, pasture was observed a greater leaf-blade proportion (Table 2) during all seasons except fall. High leaf-blade proportion could improve the forage utilization efficiency as bovines on grazing prefer to consume leaves instead of other canopy components (Hodgson, 1985). In fall, the pastures' flowering may have influenced the LP, preventing the LI effect.

Using LI95% as the appropriate time to stop the regrowth of pastures promotes the structural canopy responses that Carnevalli et al. (2006), Silva et al. (2009) and Pedreira et al. (2017) have all reported. This grazing frequency (95%LI) should allow the forage canopy to achieve greater leaf production (Table 2) at the expense of stems and dead material (Table 3). Moreover, due to the lower canopy base shading that the lesser height promotes, pastures managed with LI95% should present greater tiller population densities (Table 3), and therefore, better nutritional value (CP, NDFom and ADL in leaves) compared with the LIMax condition (Table 3).

The canopy LI variations that result from grazing frequency and intensity combinations can modify the tiller population density (Matthew et al., 1995). The highest TPD (basal and aerial) observed in LI95% pastures thus did not promote more FM. In this condition, a compensation (size/population density) between the weight and number of tillers occurs due to combinations of the pre- and post-grazing heights (Sbrissia et al., 2001). The LI95% condition allows pastures to reach the pre-grazing condition with lesser canopy height, FM, SP, DP and the ADL of leaves and stems, compared with the LIMax condition (Table 3).

Even in the post-grazing condition, LI promoted changes in the forage canopy, increasing the LP and decreasing the SP. A greater LP indicates a greater remaining leaf area, which allows the rapid regrowth of pastures without depleting the plants' organic reserves (Pedreira et al., 2007). This management practice guarantees the forage's longevity and allows the sustainable use of the production system based on tropical pastures, and may contribute to reducing pasture degradation.

Abiotic variables, including temperature, precipitation, natural chemical characteristics of the soil and fertilization, regulate the growth rate of plants (Lemaire & Chapman, 1996). In tropical regions, the seasons are divided into rainy (spring and summer) and dry (fall and winter) ones, when significant soil moisture variations occur, promoting the seasonality of plant production. The tissue appearance, growth and senescence rates of tropical forage plants are thus influenced, mainly by the availability of water and the temperature when below 15°C (Figure 1).

The seasons' effects on the forage accumulation rates are described in Table 2. As the seasons affect forage appearance rates, variations in tiller density, including basic structures for tussock formation and plant community, commonly occur. Increases in forage production result from the increase in the number of tillers, the weight of the tillers or both effects (Volenec & Nelson, 1983; Sbrissia et al., 2010). The tiller population density of Marandu palisade grass was above 1,000 tillers/m^2 even in winter (Table 5). Tillers produced in summer or fall may have remained alive during the dry season (Figure 1). Giacomini et al. (2009) observed that weather variations change tiller density mostly at the beginning and end of spring. The authors of the current study found the highest tiller density in summer (Table 5). Sbrissia et al. (2010) noted that the tiller appearance rate in palisade grass is meager from winter to mid-spring, suggesting that the cultivar's stability may be associated with a high tillers survival rate. According to these authors, tillers' extended survival makes palisade grass more resistant to stress, which maintains tiller populations and enhances pasture persistence. Small variations in tiller density are necessary to avoid weed competition with forage plants (Matthew et al., 2000).

Variations in the number and size of tillers can generally lead to differences in the stem and leaf proportions and LSR in a pasture since the reduced forage accumulation is reflected in the individual leaf accumulation. The proportion of leaves can, therefore, be reduced during autumn and winter (i.e., the dry season) and increased during spring and summer (i.e., the rainy season), promoting the same response in the LSR (Table 5). It is important to note that the leaf:stem ratio decreased over the year (Figure 1) but remained above 2.0. Furthermore, the forage nutritive value did not present seasonal variations (Table 1), contrasting the findings of Echeverria et al. (2016) and Alvarenga et al. (2020).

5 | CONCLUSIONS

Rest periods must be interrupted when the forage canopy reaches LI95%, which corresponds to a mean height of 33 cm, and grazing must be interrupted when the canopy height drops to 15 cm to manage palisade grass pastures in the Brazil's Cerrado biome effectively.

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