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Evaluation of marandu palisadegrass regrowth intervals in silvopastoral and monoculture systems

Capim marandu sob diferentes dias de rebrota em sistema silvipastoril e monocultivo

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Highlights

Deferment periods influenced canopy structure and forage accumulation.
Days of regrowth influenced the morphological composition and pasture characteristics.
Marandu palisadegrass can be cultivated in a silvopastoral system with deferment.
Silvopastoral systems: a viable option for livestock in the Brazilian Amazon.

Abstract

Silvopastoral systems (SPS) offer a sustainable alternative for animal production in tropical ecosystems. This study aimed to evaluate the effects of deferment days on herbage accumulation, plant-part composition, and canopy structural characteristics of Marandu palisadegrass (*Urochloa brizantha* Hochst. ex A. Rich.) in SPS with *Eucalyptus urophylla* and monoculture (MC). The experiment was conducted using a randomized block design, with each system individually allocated at the center of each plot in a 3 x 4 factorial arrangement, consisting of three systems: monoculture, and silvopastoral systems with tree row spacings of 12 m and 18 m, and tree intra-row spacing of 2 m, across four regrowth periods (60, 90, 120, and 150 days), each with three replications. Increasing deferment days reduced the proportion of green components in the forage, affecting tiller population density (TPD), leaf dry mass (LDM), and leaf/stem ratio. Maximum LDM production occurred at approximately 88 days with 0.63 Mg ha^{-1}, while peak green dry mass (GDM) was at 94 days, reaching 1.11 Mg ha^{-1}. Both dead material

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dry mass (DMDM) and total dry mass (TDM) increased linearly with regrowth periods, although TDM comprised about 47% dead forage. A regrowth period of 94 days from March is feasible for Marandu palisadegrass in SPS with 12 m and 18 m between tree rows, demonstrating that this spacing does not hinder forage production.
Key words: Diversified system. Forage accumulation. Leaf dry matter. Morphologic composition. Tillers.

Resumo

Os sistemas silvipastoris (SSP) são uma alternativa sustentável para a produção animal no ecossistema tropical. Nosso objetivo foi avaliar o efeito dos dias de diferimento no acúmulo de forragem, na composição das partes da planta e nas características estruturais da copa do capim-marandu *Urochloa brizantha* (Hochst. ex A. Rich.) em SPS com *Eucalyptus urophylla* e monocultivo (MC). O experimento foi realizado de março a agosto de 2019 e 2020, respectivamente, em delineamento de blocos completos casualizados onde cada sistema foi alocado individualmente no centro de cada parcela em arranjo fatorial 3 x 4 formado com três sistemas: monocultivo, sistema silvipastoril com espaçamento de 12 e 18 m entre as fileiras de árvores, com 2 m entre árvores dentro das fileiras e quatro períodos de rebrota (60, 90, 120 e 150 dias) com três repetições. O aumento dos dias de diferimento reduzem a participação de componentes verdes na forragem, como densidade populacional de perfilhos (DPP), massa seca foliar (MSF), e reduz a relação folha/colmo. A produção máxima de massa seca foliar (MSF) ocorreu aproximadamente aos 88 dias com 0,63 Mg ha^{-1}, a massa seca verde (MSV) foi aos 94 dias atingindo 1,11 Mg ha^{-1}. A massa seca de material morto (MSMS) e a massa seca total (MST) tiveram comportamento linear crescente conforme os períodos de rebrota, mas a MST apresentou cerca de 47% de forragem morta em sua composição. É possível adotar um período de diferimento de 94 dias a partir de março utilizando capim Marandu em sistema silvipastoril com espaçamento de 12 e 18 m entre as fileiras de árvores, este arranjo não é obstáculo na produção de forragem.
Palavras-chave: Sistema diversificado. Acúmulo de foragem. Massa seca foliar. Composição morfológica. Perfilhos.

Introduction

Forage cultivation is the primary food source for the Brazilian herd raised on pasture. However, inadequate management leads to pasture degradation, necessitating the renewal or recovery of approximately 8 million hectares annually, often within integrated systems like silvopastoral systems (Jank et al., 2014). Silvopastoral systems (SPS) integrate trees, pastures, and livestock in a single area, optimizing the use of soil, plants, and animals (Cabral et al., 2017).

As a conservation-oriented model, SPS plays a crucial role in mitigating land degradation, offering economic diversification, enhancing biodiversity, and potentially increasing economic returns (Yadav et al., 2014). These systems maintain soil moisture, improve microclimate conditions, and provide better thermal comfort for animals, thus promoting their welfare (Deniz et al., 2019).

The management of cultivated pastures must overcome challenges like productivity barriers in degraded, low-fertility areas and seasonal forage production variability due to water scarcity, leading to feed shortages for pasture-raised livestock. Deferred grazing, an approach involving the temporary exclusion of livestock to allow forage accumulation for off-season use, is a viable solution to this issue due to its simplicity and cost-effectiveness (A. D. D. Santos et al., 2020). Pasture deferment, involving varying regrowth periods, entails closing off a pasture area to exclude animals, thereby allowing forage to accumulate. This accumulated forage is then utilized for animal feeding during the off-season, ensuring a consistent food supply.

Careful planning is essential for both silvopastoral systems and deferred grazing pastures. Long deferment periods can reduce the palatability and nutritional value of the forage, characterized by decreased green leaf content (Oliveira et al., 2020; Di Loreto et al., 2019). In SPS, excessive shade can negatively affect forage quality, leading to stem elongation and higher fiber content, which are not ideal for animal consumption (Cabral et al., 2017; Gomes et al., 2019).

This study hypothesizes that a well-managed SPS can effectively address plant morphological and physiological changes to sustain pasture productivity, thereby supporting sustainable production systems. To examine this hypothesis, we investigated Marandu palisadegrass in both silvopastoral and monoculture systems, focusing on forage accumulation, plant part composition, and canopy structural characteristics in the Brazilian Amazon biome.

Materials and Methods

Experimental Site

The study was conducted at the experimental farm of the Federal Institute of Education, Science, and Technology of Tocantins, Colinas do Tocantins campus, situated in the state's northern region along the BR-153 road, at coordinates 8°05′22″ S latitude and 48°28′33″ W longitude, and an elevation of 223 meters. The local climate is classified as AW (hot and humid) according to Köppen's system (Alvares et al., 2013), with a dry season extending from May to September. The region experiences an average annual temperature of 28°C and receives an average annual rainfall of 1,800 mm. Figure 1 displays the maximum and minimum temperatures and rainfall that occurred during the experimental period.

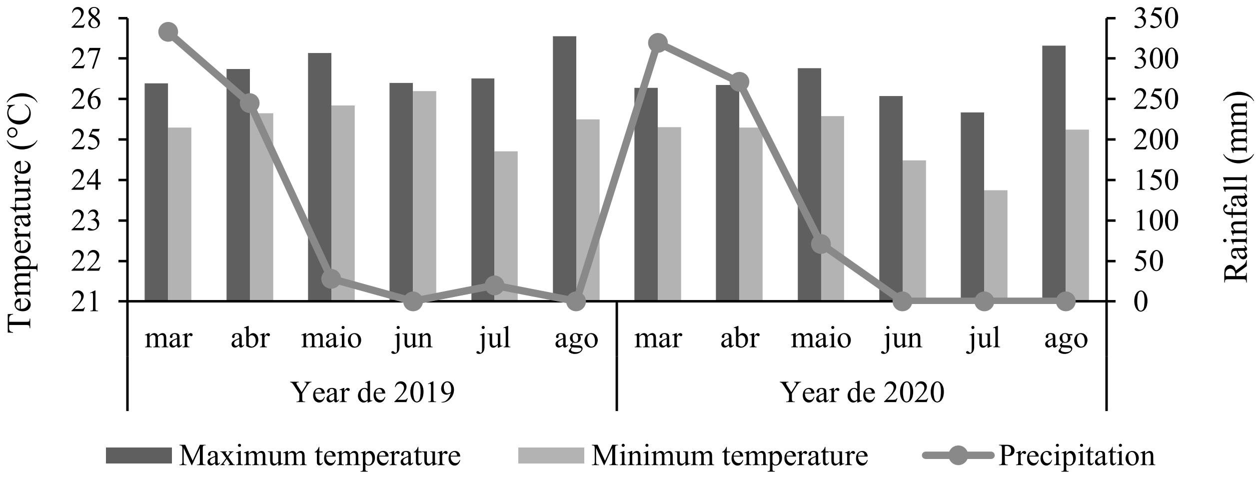

Figure 1. Rainfall, maximum and minimum temperatures during the experimental from March to August in both 2019 and 2020. Colinas, TO, Brazil.

The experimental area spanned 1.2 hectares, initiated in 2016 with *Eucalyptus urophylla* planting. In the Silvopastoral System, tree rows were aligned east-west, maintaining 2 m between trees within rows and varying inter-row distances of 18 m (18m × 2m) and 12 m (12m × 2m). Marandu palisadegrass was cultivated between these rows. The monoculture area solely comprised Marandu palisadegrass. The experimental phase ran from March to August in both 2019 and 2020. Soil samples from the top 0-20 cm layer were analyzed for physicochemical properties (Table 1), identifying the soil as a typical Orthic Quartzarenic Neosol (H. G. Santos et al., 2018).

Table 1
Chemical and physical analysis of the soil from the 0- to 20-cm depth layer under a silvopastoral system and monoculture system

System	pH	OM†	P (Mehl.)	*Ca*	Mg	K	H + Al	SB‡	CEC§	BS¶
	$CaCl_2$	g dm^{-3}	Mg dm^{-3}		cmolc dm^{-3}					%
SPS 12m	4.9	16	0.9	1.1	0.8	0.01	1.7	1.9	3.6	53
SPS18m	4.9	16	0.9	1.1	0.8	0.01	1.7	1.9	3.6	53
Monoculture	4.7	13	0.9	1.8	0.6	0.07	1.9	2.4	4.4	56

† OM, organic matter. ‡ SB, sum of bases. § CEC, cation exchange capacity at pH 7. ¶ BS, base saturation.

On March 16 of both 2019 and 2020, standardization cuts were made to maintain a stubble height of 20 cm. A single annual maintenance fertilization was applied each year, adhering to the grass's nutritional needs and the system's technological standards as described by P. M. Santos et al. (2010a). This included the application of 50 kg ha-¹ of nitrogen (N) using urea, 70 kg ha-¹ of phosphorus (P) as simple superphosphate (P_2O_5), and 50 kg ha-¹ potassium chloride (K_2O) to replenish nutrients for optimal grass growth.

Treatments and experimental design

The experiment was carried out using a completely randomized block design, with each system individually allocated to the center of each plot, which measured 670 m². Treatments corresponding to different regrowth periods (60, 90, 120, and 150 days) were arranged in a 3 x 4 factorial design, encompassing three systems (monoculture and silvopastoral with 12 m and 18 m spacing between trees in rows) and four deferment periods (60, 90, 120, and 150 days). This resulted in twelve treatments, each replicated three times, leading to a total of 36 plots.

Pasture measurements

During each growth cycle, the total dry mass (TDM) was measured by sampling the forage within two quadrats, each sized 0.5 m x 0.5 m, at a height of 20 cm. The herbage accumulation rate was determined by dividing the TDM by the rest period duration in each cycle. The herbage mass collected above 20 cm after each cycle contributed to the calculation of seasonal accumulation and the experiment's overall TDM.

To analyze the TDM plant-part composition at the end of each cycle, a subsample was categorized into leaf (leaf blade), stem (stem + leaf sheath), and dead material (DMDM). Subsequently, each plant part was dried at 55°C in a forced-air dryer until reaching a constant weight. Canopy height was measured at six random points before harvest. With the quadrat frame still in position, tillers within the frame were counted to determine the tiller population density (TPD).

Statistical analysis

The data underwent Shapiro-Wilk tests for normality and tests for homoscedasticity to validate the assumptions of the statistical methods used. The systems were assessed using analysis of variance (ANOVA) and regression analysis to understand the effects of deferment periods. All statistical analyses were conducted at a significance level of $p = 0.05$, ensuring that the results were statistically significant. These analyses were carried out using the SISVAR 5.3 software, a tool for statistical analysis and design of experiments (Ferreira, 2011).

Results and Discussion

The analysis of variance revealed that deferment days significantly affected all evaluated parameters (Figure 2). There was no significant interaction between the system type and the deferment period for the variables analyzed. Tiller population density (TPD) showed a negative linear trend with increased deferment days (Figure 2a), with an average TPD across systems of 352.44 per m². A decline in tillering is undesirable in pastures, as it impacts forage accumulation negatively.

Extended regrowth periods allow existing tillers to shade the base of the plant, reducing light availability essential for the physiological processes vital for basal tillering, leading to its suppression (Oliveira et al., 2020). Tillering is influenced by numerous factors, including time. Different deferment durations illustrate their impact on the grass tillering process; overly long growth periods can adversely affect vegetative tiller production, causing them to become reproductive and eventually senesce (Vilela et al., 2013; Gouveia et al., 2017).

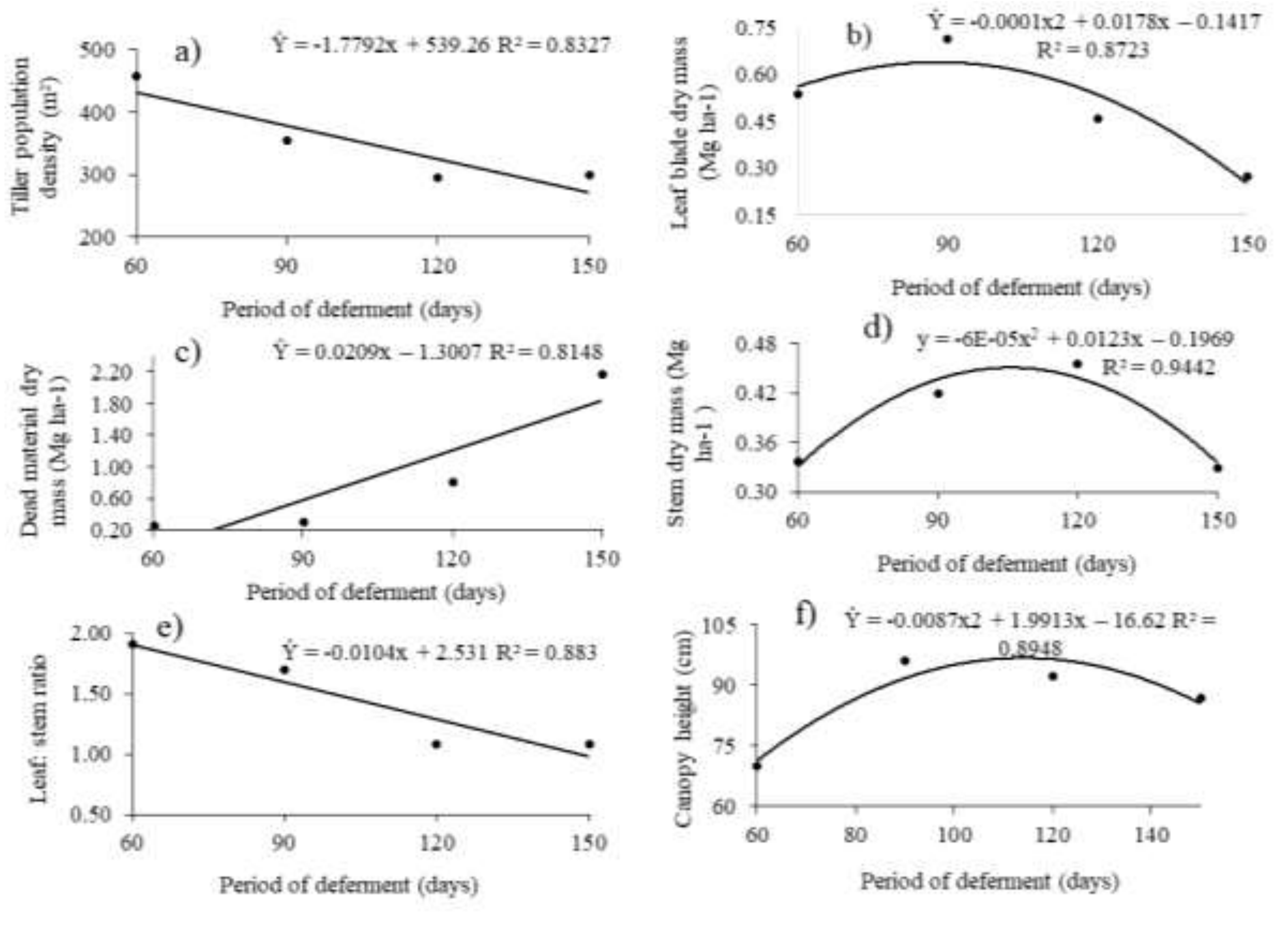

Figure 2. Tiller population density (a), leaf blade dry mass (b), dead material dry mass (c), stem dry mass (d), leaf: stem ratio (e), and pasture height (f) of Marandu palisadegrass under silvopastoral (SPS) and monoculture (MC) system and different deferment periods.

Under conditions without limitations, plant tissues continually renew. However, under restrictive conditions, plants prioritize sustaining existing tissues over developing new ones. Alves et al. (2019) noted a surge in tiller emergence only during the initial stages of deferment, with a subsequent decline even when nitrogen fertilization was applied, as the deferment period progressed.

The spacing adopted in the study did not hinder tillering, as there were no significant differences among the systems. This finding is important because excessive shading from tree canopies can potentially limit grass production in silvopastoral systems (Lopes et al., 2017). It suggests that factors other than spacing, possibly water availability, might have more influence on the observed results. Regarding the accumulation of leaf blade dry mass (LDM) (Figure 2b), a decrease was noted with increasing deferment, and a quadratic model provided the best fit ($p<0.05$), indicating maximum leaf production at around 88 days of recovery, yielding 0.63 Mg ha^{-1}.

No significant differences were observed in LDM across the systems ($p = 0.786$), with an average of 0.48 Mg ha-1. The trend of decreasing living leaf blades with prolonged deferment aligns with Oliveira et al. (2020) findings. Since leaf accumulation is crucial for pasture recovery to support animal performance, management practices should focus on maximizing this component.

Adverse environmental conditions may lead to reduced tillering and, consequently, a decline in new leaf synthesis, prioritizing the growth of existing leaves that eventually become senescent tissue. This pattern results in decreased live leaf blades and tillering as the deferment period extends, supporting the observations made by Oliveira et al. (2020). Increased dead forage not only diminishes the nutritional value but also impacts the consumption and performance of grazing animals. The buildup of senescent tissue in pastures under extended recovery periods is a known phenomenon (M. E. R. Santos et al., 2010c; Vilela et al., 2012), underscoring that pasture management strategies directly influence forage productivity.

Contrary to the production trends observed for TPD and LDM, the accumulation of DMDM increased with the deferment period, displaying a linear upward trend ($p < 0.05$) (Figure 2c). At 150 days of deferment, DMDM reached 2.18 Mg ha^{-1}. This rise in DMDM correlates with reductions in LDM and TPD, as these parameters are inversely related: longer deferment periods result in fewer green leaves and live tillers (M. E. R. Santos et al., 2010b), leading to an increase in senesced material.

Shading tends to maintain grass in a physiologically younger state, reducing senescence and dead material accumulation by prolonging the vegetative phase compared to grass in monoculture (Lopes et al., 2017). However, in this study, there was no significant interaction between system type and deferment intervals, suggesting that the tree-induced shading was not sufficient to alter phenological processes. The east-west planting direction likely contributed to minimizing the effects of excessive shading.

As deferment progresses, forage grows to maximize light interception, leading to competition and stem elongation as plants seek light exposure at the canopy's top. Over time, stem mass increases while green leaf mass decreases until tissue senescence sets in (Loreto et al., 2019).

Stem dry mass (SDM) demonstrated a quadratic response (p = 0.03) (Figure 2d), with no significant differences between SPS12, SPS18, and MC systems (p = 0.20). Average SDM values were 0.35, 0.43, and 0.36 Mg ha^{-1} for each system, respectively. The peak of stem accumulation occurred at 105 days of deferment, with 0.45 Mg ha^{-1}. These regrowth-period-related pasture characteristics reflect the impact of specific management practices, leading to expected increases in dead material and stem mass with extended deferment durations (M. E. R. Santos et al., 2010b,c; Vilela et al., 2012).

The leaf/stem (L/S) ratio demonstrated a linear decline ($p < 0.05$) with increasing days of pasture recovery (Figure 2e), with the highest ratio observed at 60 days of deferment. There was no significant difference in the L/S ratio among the evaluated systems ($P > 0.05$), with an overall mean of 1.44 cm. The L/S ratio is a crucial indicator of pasture quality since a higher stem volume in the pasture implies lower nutritional value and does not align with the primary dietary component of grazing animals. Extended deferment leads to a pasture with a morphological composition and nutritional value that limits animal performance, notably reducing the percentage of live leaves (M. E. R. Santos et al., 2016), with these components eventually turning into dead material as abiotic conditions become more limiting.

The grass showed a quadratic response in height to deferment periods ($p < 0.05$) (Figure 2f), peaking at 97 cm around 114 days, followed by a decrease, with no significant difference among systems (p = 0.05). The average height was 86.33 cm, with the MC system showing an 11% higher production compared to SPS12 and SPS18 (Table 2).

Table 2
Total (TDM), green (GDM), and dead material (DMDM) dry masses of Marandu palisadegrass under silvopastoral (SPS) and monoculture (MC) systems

System	TDM (Mg ha^{-1})	*p*-value	GDM (Mg ha^{-1})	*p*-value	DMDM (Mg ha^{-1})	*p*-value
MC	1.94 A		0.85 A		1.09 A	
SPS12	1.63 B	<0.0189	0.84 A	<0.1732	0.79 B	<0.0328
SPS18	1.74 AB		0.93 A		0.80 B	
CV (%)	20.76		21.43		25.12	

SPS12 and SPS18 - Silvopastoral systems with 12 m and 18 m between the rows of trees. Means followed by the same letter in the column do not differ according to the Tukey test at the 5% probability level. CV: Coefficient of variation.

Total dry mass (TDM) accumulation in Marandu palisadegrass was influenced by the days of deferment ($P < 0.05$) (Figure 3), peaking after 120 days but with 47.23% comprising dead forage. TDM showed a linear increase with extended recovery periods, reflecting the plants' capacity to utilize environmental resources for growth and development over time (Vilela et al., 2012). This growth is crucial for ensuring sufficient forage to support the herd and achieve optimal stocking rates during limited food availability periods (Gouveia et al., 2017).

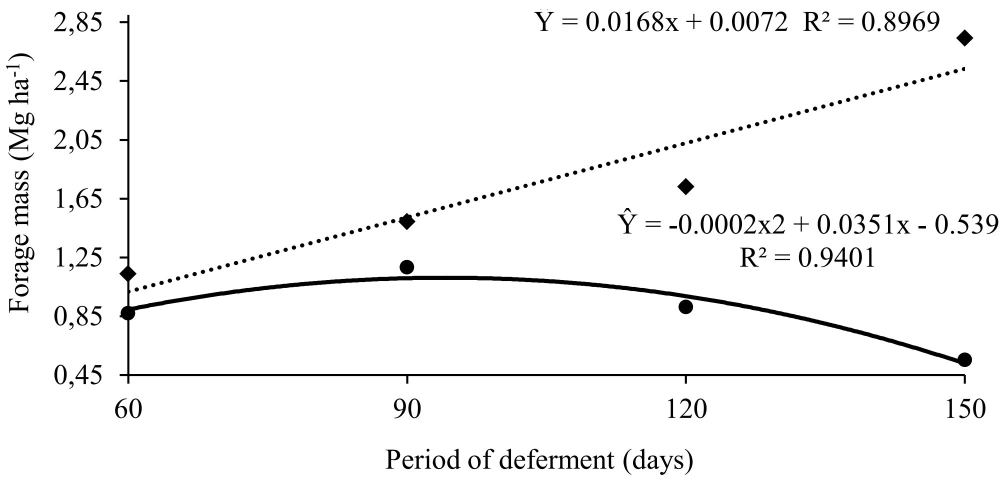

Figure 3. Total (TDM- ♦) and green (GDM- ●) dry masses of Marandu palisadegrass under silvopastoral (SPS) and monoculture (MC) systems under different deferment periods.

The SPS arrangement did not adversely affect forage productivity, comparable to the MC system. However, the proportion of senescent material in TDM at 120 days (47%) was substantially higher than the less than 10% reported by Prado et al., (2019). Animals prefer fresh, nutritionally rich leaves at the canopy's top, making LDM the crucial fraction available to them, impacting their performance. Thus, reducing the deferment period can be a strategic management practice to enhance cattle selectivity and optimize pasture utilization (M. E. R. Santos et al., 2016).

The quadratic model best fits the green dry mass (GDM) production data ($P < 0.05$), with the grass reaching its peak production at 94 days of deferment, achieving 1.11 Mg ha^{-1} of fresh dry mass. While the monoculture (MC) and silvopastoral system with 12 m spacing (SPS12) differed in terms of TDM (Table 2), with MC showing higher mean values, there was no significant difference in GDM production between the systems ($p = 0.17$).

TDM and leaf dry mass (LDM) exhibited opposing trends concerning deferment periods, suggesting that a massive portion of TDM consists of low-nutritional-value dead material. Silvopastoral systems should be designed to prevent excessive shading, which could hinder grass growth and biomass production (Pandey et al., 2011; Pezzopane et al., 2019).

Water stress appears to be a primary factor limiting forage accumulation rates and the dry mass of accumulated forage during the dry season, aligning with the findings of this study (Santos et al., 2016). Optimal productivity and desirable morphological composition are achieved with shorter pasture-recovery periods.

These findings concur with Paciullo et al. (2009), who noted that neither grass development nor animal performance was negatively impacted in a silvopastoral system under moderate shading. In this study, water limitation might have specifically influenced the response of Marandu palisadegrass to deferment periods. It is typical for forages in shaded environments to grow taller as a morphological adaptation to seek light exposure at the canopy's top (Paciullo et al., 2011), a trend not affected by the type of system but encouraged by the plant's self-shading.

Extended deferment encourages tissue growth and elongation, enabling plants to achieve greater heights (Prado et al., 2019; Loreto et al., 2019; Gouveia et al., 2017). Although reducing regrowth days decreases TDM, it results in a forage composition more suitable for animal consumption, characterized by lower stem dry mass (SDM), dead material dry mass (DMDM), higher LDM, and a better L/S ratio.

Conclusions

The findings from our study indicate that Marandu palisadegrass is suitable for intercropping within a silvopastoral system, with tree row spacings of 12 and 18 meters aligned in an East-West direction, without compromising its structural integrity and productivity compared to its monoculture. By considering both production levels and morphological characteristics, it is feasible to implement a deferment period ranging from 88 to 94 days starting in March for Marandu palisadegrass in a silvopastoral setup.

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