

EFFECT OF SHADING ON AGRONOMIC AND STRUCTURAL CHARACTERISTICS OF MOMBAÇA GRASS IN AGROFORESTRY SYSTEM IN THE CERRADO-AMAZON ECOTONE

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ABSTRACT

The search for sustainability in integrated production systems is a constant challenge, especially when it comes to balancing the levels of shading provided by trees in agroforestry systems. The objective of this study was to evaluate the effects of three shading levels (0, 30 and 60%) casted by native Babaçú trees (*Attalea speciosa*, Mart) on the agronomic and structural characteristics of Mombaça grass in the ecotone Cerrado-Amazon. A total area of 3 ha was stratified into 36 subdivisions measuring 270 m² each, in order to collect agronomic samples from the three shading levels, totaling 108 experimental units, where the structural and agronomic characteristics of Mombaça grass were assessed. Increased shading leads to reduction in tiller population density, forage volumetric density, leaf area index and yield and proportion of morphological components of Mombaça grass, reducing forage yield. The 65% and 78% reduction in tiller population in areas with 30 and 60% shading, respectively, in comparison to full sun light exposure, was the main factor in the reduced productivity of the grasses managed in the agropastoral system. Therefore, Mombaça grass should be managed at a level of 30% shading, which can be considered adequate to maximize forage yield, balancing the benefits of soil and water conservation with the possible negative impacts on forage production.

Keywords: Integrated systems, *Megathyrus maximus*, sustainability, tillering, tropical forage.

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INTRODUCTION

As agricultural systems expand, in the quest to increase productivity and the quantity of food produced, other concerning issues aggravated in traditional agricultural systems have emerged, such as soil loss, erosion, loss of fertility, reduction of soil meso- and macro-fauna, soil compaction and acidification (Melo *et al.*, 2015; Oliveira and Wolski, 2012), as well as the excessive use of certain agricultural inputs that can lead to the emission of greenhouse gases and the eutrophication of groundwater (Anas *et al.*, 2020).

Ruminant production in Brazil is largely represented by a production system based on tropical pastures, which covers an area of approximately 18.72% of the national territory. However, in 2020, 38.89% of these areas were classified as intermediately degraded and 15.78% as severely degraded (LAPIG, 2023), causing major economic losses due to low productivity per area, loss of productive vigor, increase in areas with bare soil, which facilitates soil disintegration, and loss of soil fertility, causing instability of grasses (Fidelis *et al.*,

2011; Santos *et al.*, 2022). Santos *et al.* (1998) reported soil loss of 22.4 tons ha⁻¹ in pasture areas over a 15-month period and 151.2 tons ha⁻¹ of loss in areas with bare soil. This emphasizes the need for conservation practices that promote productivity without compromising soil fertility with low environmental impact (Ibrahim *et al.*, 2006; Oliveira *et al.*, 2009).

Agroforestry systems have emerged as sustainable farming alternatives, due to the benefits of incorporating the tree component in soil preservation, water conservation, as well as improving the soil physical, chemical and biological characteristics (Simões *et al.*, 2023; Suárez *et al.*, 2021). The presence of trees in pasture areas improves the effects of the microclimate, mitigating lower temperatures due to less solar radiation, making the environment more comfortable for the animals, which also influences animal performance (Deniz *et al.*, 2023). Recently, agroforestry systems have been highlighted as natural climate solutions to help substantially mitigate climate change and the sustainability of agricultural systems (Hart *et al.*, 2023).

However, the restriction of light caused by trees is one of the main factors limiting pasture productivity in

a shaded environment, which prevents photosynthetically active radiation from reaching the understory (Belesky, 2005), thus limiting the photosynthetic rates of grasses (Gomes *et al.*, 2019) and consequently reducing forage yield (Santos *et al.*, 2016). Depending on the level of sunlight reduction in the forage canopy, forage plants can be affected. In addition, competition for water and nutrients can also occur between trees and pastures grown in the understory, however, the effect of competition is not very pronounced in a system with native trees, since their root systems explore deeper layers when compared with forage grasses.

Santos *et al.* (2016) found that intense shading can lead to the death of leaves and tillers, and consequently alter the structure of the forage canopy, which contributes to maintaining a negative carbon balance and reduce growth under the shade. It is known that tolerance to shading can be a function of the morphophysiological adaptations of each forage species in order to maintain the structure of the forage canopy and good productive capacity. Paciullo *et al.* (2017) studied the morphogenic and structural characteristics and biomass production of grasses of the genus *Megathyrsus* under different levels of artificial shading (0, 37 and 58%) and found that moderate shading (37%) resulted in less severe reductions in tiller density in comparison to severe shading (58%).

It is, therefore, essential to study the effects of synergism between native trees and tropical forage grasses, and to observe their morphophysiological adaptations under different levels of shading, as they are necessary for the proper planning of the spatial

arrangement of the tree component in agroforestry systems, as well as to define the proper management of forage grasses in integrated systems. The hypothesis of the present study is that Mombaça grass grown in the presence of native Babaçú trees (*Attalea speciosa*, Mart) would respond differently to structural and agronomic changes under shading levels. Therefore, this study was carried out in an agroforestry area, integrating native Babaçú trees and *Megathyrsus maximus* cv. Mombaça pasture, to evaluate the agronomic and structural characteristics of the grass under different levels of shading in the Cerrado-Amazon ecotone.

MATERIALS AND METHODS

The experiment was conducted at Brejão Farm owned by the School of Veterinary Medicine and Animal Science of the Federal University of Northern Tocantins (EMVZ-UFNT), Araguaína Campus, Tocantins, Brazil. The climate of the region is classified as Aw, hot and humid (Köppen, 1948), with a well-defined dry season from June to September, and average temperature, air relative humidity and rainfall of 28°C, 78% and 1800 mm, respectively. The experiment was conducted during the rainy season, from December to June, 2017.

The soil of the experimental area was classified as Eutrophic Red Printhic Argisol (Santos *et al.*, 2018), presenting a slope of 3%. In November, a composite soil sample was collected at a depth of 0-20 cm to determine its chemical composition (Claessen, 1997) (Table 1).

Table 1: Chemical characteristics of the soil in the experimental area at implantation, in the 0-20 cm depth layer.

System	pH	OM	P	K	Ca	Mg	Al	H+Al	SB	CEC ¹	V
	CaCl ₂	g dm ⁻³	mg dm ⁻³				-----cmol.cdm ⁻³ -----				%
SPS30	5.58	0.90	3.01	0.21	6.61	2.13	0.295	4.42	8.95	13.37	66.94
SPS60	5.14	0.21	2.08	0.29	9.59	3.25	0.265	5.41	13.13	18.72	71.10
Monoculture	5.34	0.42	3.31	0.27	4.04	2.85	0.3	6.16	7.16	13.32	53.75

SB: sum of bases; CEC¹: cation exchange capacity at pH 7.0; V%: base saturation.

According to the chemical analysis of the soil (Table 01), an application program of correctives and fertilizers was determined in order to provide adequate nutrients for the development of the grass. The soil pH was corrected by applying 2 Mg ha⁻¹ of dolomitic limestone in the silvopastoral system (SPS30 and SPS60) and 1 Mg ha⁻¹ in the area fully exposed to the sun to raise the base saturation above 60%. The soil was fertilized in November. Nitrogen fertilization (150 kg ha⁻¹ year⁻¹ of nitrogen) was split, with the first application (50 kg ha⁻¹ of N) being made at the start of the evaluation period and the rest over the harvest cycles, using urea as the source of N. Phosphorus was applied in the form of superphosphate in the amount of 60 kg ha⁻¹ of P₂O₅ in all

production systems. Potassium application was distributed over the harvest cycles in the form of potassium chloride (120 kg ha⁻¹ year⁻¹ of K₂O).

The experimental area has a history of being cleared for pasture for more than 25 years, part of which was abandoned. After pasture degradation, a secondary forest was created with a strong presence of Babaçú (*Attalea speciosa*, Mart), which is a shrub species measuring up to 4 m in height and over 8 cm in diameter (Santos *et al.*, 2018). Mombaça grass (*Megathyrsus maximus* cv. Mombaça) was sown in November 2011 at a rate of 7 kg ha⁻¹ of seeds, with planting and fertilization carried out manually.

The experimental areas consisted of three production systems, with different levels of shading, as described below:

1. Monoculture: Mombaça grass pasture (*Megathyrus maximus* cv. Mombaça) planted in a 1-ha area of sparse, treeless forest, under full sun exposure (monoculture), established in 2011, with a medium level of intensification.
2. Silvopastoral System SPS30: 1ha of Mombaça grass pasture with native Babaçú trees (*Attalea speciosa*, Mart) established in 2011. The area was manually thinned to provide a 30% shading level, which was determined using a lux meter (Model LD 200). These measurements were taken at 50 spots within the SPS30 on a grid constructed in an equidistant and representative way (8 x 8). The light readings were taken between 6am and 1pm, and compared with the fully sun-exposed area readings, according to the equation: $100 - \{(SPS \text{ reading} / FS \text{ reading}) * 100\}$.
3. Silvopastoral system SPS60: 1ha of Mombaça grass pasture with native Babaçú trees (*Attalea speciosa*, Mart) established in 2011. This area had the same thinning management as SPS30, but the shading level was adjusted to 60%.

Each studied environment was stratified into 36 subdivisions measuring 270 m² each. Data were collected from three levels of shading (0, 30 and 60%) and two production systems (silvopastoral and monoculture), totaling 108 experimental units. The production systems were allocated independently and then compared. The experimental model was:

$$y_{ij} = \mu + \alpha_i + b_j + e_{ij}$$

where: y_{ij} = record of the j^{th} replication of the i^{th} shading level; μ = general average; α_i = effect due to the i^{th} shading level; b_j = effect due to the j^{th} replication; e_{ij} = error associated to replication (ij).

The uniformization cut was carried out in December, adopting a post-cut residue height of 40 cm. The rest period was variable for an average canopy height of 90 cm (Silveira Junior *et al.*, 2017). The Mombaça grass height was monitored with a graduated ruler, by measuring 10 random spots per experimental unit. In each reading, the average height of the canopy at the measurement spot was recorded, and the average height of the 10 spots corresponds to the average of the experimental unit. Samples were taken at two sampling sites at representative spots of the average canopy height per experimental unit, using a 0.50 x 1.0 m (0.5m²) sampling frame, and a cleaver to determine the forage yield (ton ha⁻¹) of the harvestable extract, at a height of 40 cm from the ground, which was quantified and packed in labeled bags. Forage was collected from 36 replications in each system.

Morphological components of the harvestable extract, such as leaf blade, stem + leaf sheath and dead material, were obtained from a sub-sample. These components were then placed in duly identified paper bags and taken to a forced-air circulation oven to dry at 55°C for 72 hours until they reached a constant mass.

The agronomic and structural attributes of Mombaça grass assessed under the three shading levels (0, 30 and 60% shading) were: height (cm), total dry biomass yield (TDB, ton. ha⁻¹), morphological components - stem, leaf blade and dead material (ton. ha⁻¹); and the proportion of morphological components - leaf blade, stem (stalk) plus leaf sheath, dead material, leaf:stem ratio, leaf area index (LAI), forage volumetric density (ton. ha⁻¹ cm⁻¹), number of tillers (unit m⁻²) and mass per tiller (g tiller⁻¹).

The responses referring to the structural and agronomic variables of Mombaça grass under the different shading levels were subjected to normality (Shapiro-Wilk) and homoscedasticity (Bartlett) tests, and posterior analysis of variance in the statistical software SAS through the command *proc GLM*, and the effects of shading levels were compared using quadratic or linear ($p > 0.05$) regression equations. The equation was chosen based on the highest coefficient of determination, significance of regression and significance of the response variable.

RESULTS

The shading levels had no effect on canopy height ($p > 0.05$); however, it affected forage yield (Figure 1), which was lower under 60% shading (1.63 ± 0.6 ton ha⁻¹) and higher under full sun (6.6 ± 0.15 ton ha⁻¹). The harvestable forage yield of Mombaça grass linearly decreased as the shading levels increased (Figure 1), showing a reduction of 8.26 ton ha⁻¹ of forage dry matter for every 10% reduction in the incidence of light reaching the understory, corresponding to a 65 and 78% reduction in the tiller population in areas with 30 and 60% shading, respectively, compared with full sun.

The number of tillers was strongly affected by the level of shading, showing quadratic responses ($p \leq 0.05$), but with no effect on tiller mass ($p > 0.05$), with maximum reduction obtained with 51.88% equivalent shading (Figure 2), lower values in environments with 60% shading (117 ± 28 m²) and higher values under full sun (534 ± 123 m²).

The volumetric density of the forage was also affected by the level of shading, showing quadratic responses ($p \leq 0.05$), with the maximum reduction obtained at 48.07% equivalent shading (Figure 2), lower values observed in environments with 60% shading (0.15 ± 0.001 ton DM cm⁻¹ ha⁻¹) and higher values under full sun (0.03 ± 0.001 ton DM cm⁻¹ ha⁻¹). The leaf:stem ratio was not affected ($p > 0.05$) by the shading.

The shading level affected the yield of morphological components of Mombaça grass ($p \leq 0.05$) (Figure 3), whose production of leaf blade and stem was adjusted to the decreasing linear regression model, showing a reduction of 0.7 ton ha⁻¹ and 0.5 ton ha⁻¹ for each 10% increase in shading, respectively, with the lowest values observed in environments with 60%

shading, 1.42 ± 0.5 ton DM ha⁻¹ of leaf blade and 0.13 ± 0.001 ton DM ha⁻¹ of stem, and the highest values under for full sun, 5.62 ± 1.54 ton DM ha⁻¹ of leaf blade and 0.57 ± 0.001 ton DM ha⁻¹ of stem. Quadratic effect was observed for the yield of dead material, with the lowest value observed under 30% shading.

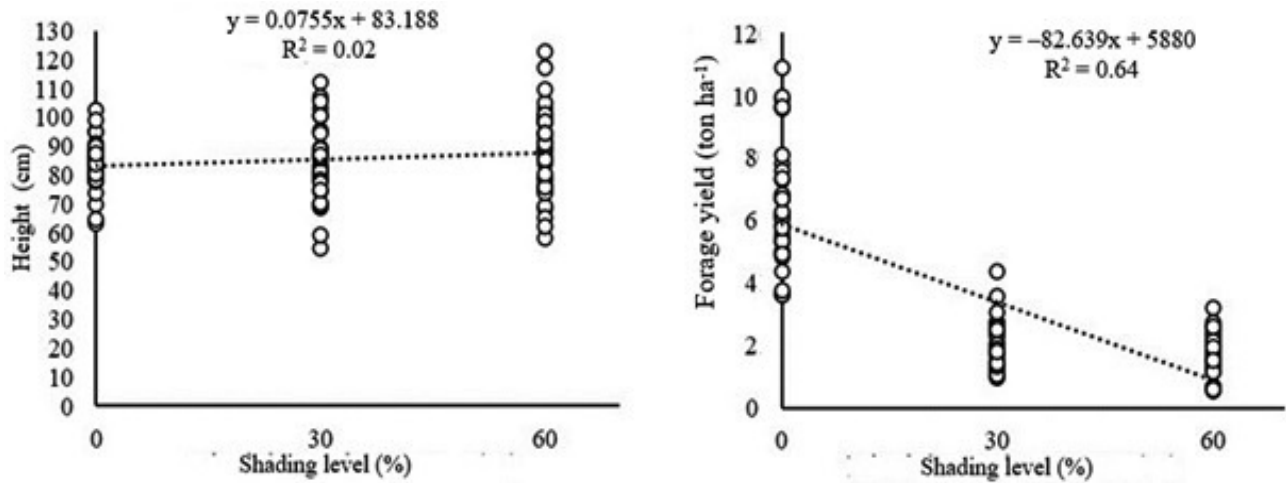


Figure 1: Height and forage yield under different shading levels.

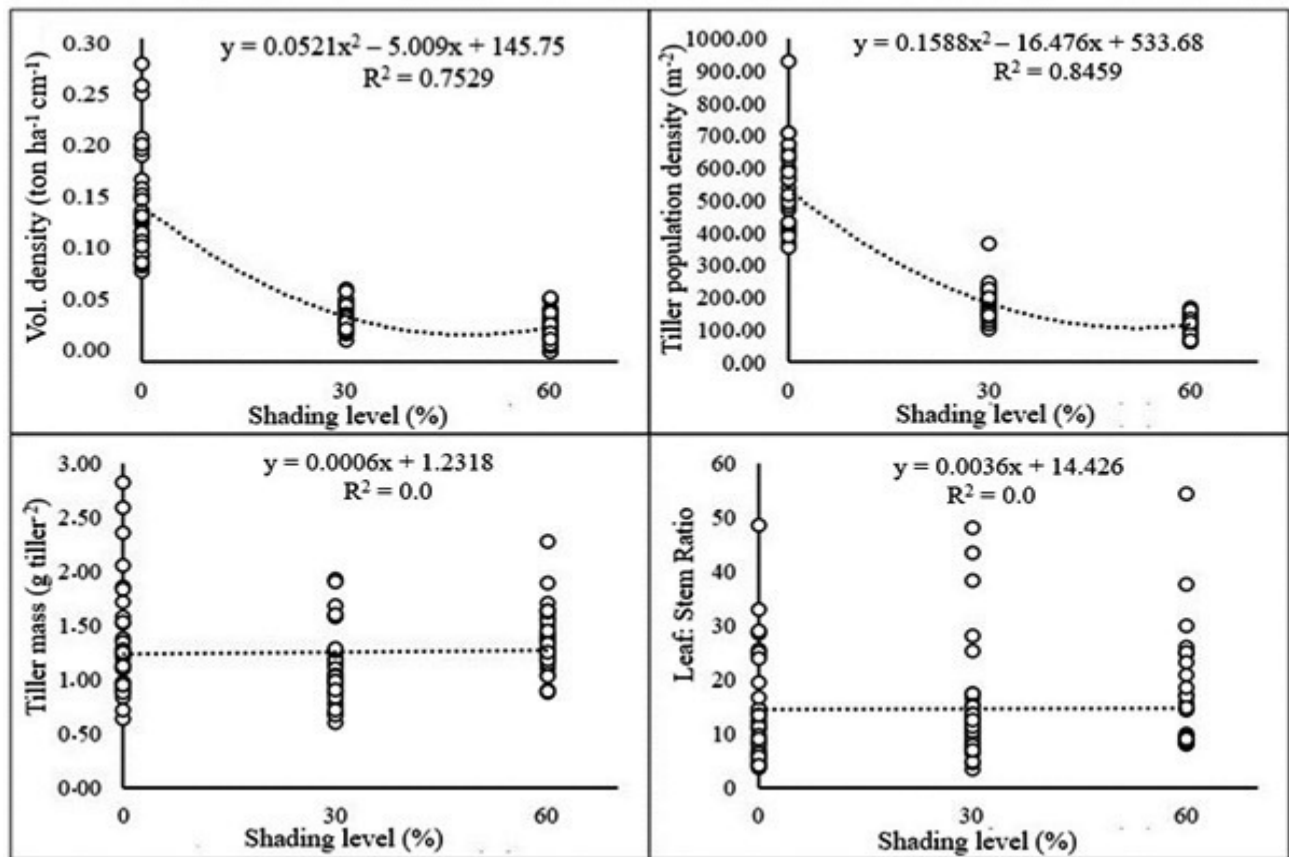


Figure 2: Volumetric density, tiller population density, mass per tiller and leaf:stem ratio of Mombaça grass grown under three shading levels in Araguaína – Tocantins.

There was also effect ($p \leq 0.05$) on leaf area index (LAI), which decreased linearly as the shading increased (Figure 3), showing a reduction of one leaf area unit for every 11% increase in shading, with the lowest values observed in environments with 60% shading (2.0

$\pm 1.0 \text{ m}^2$) and the highest values under full sun ($8.0 \pm 2.0 \text{ m}^2$). The proportion of leaf blade and dead material was affected by the level of shading ($p > 0.05$), whereas the proportion of stem was not affected ($p > 0.05$) (Figure 4).

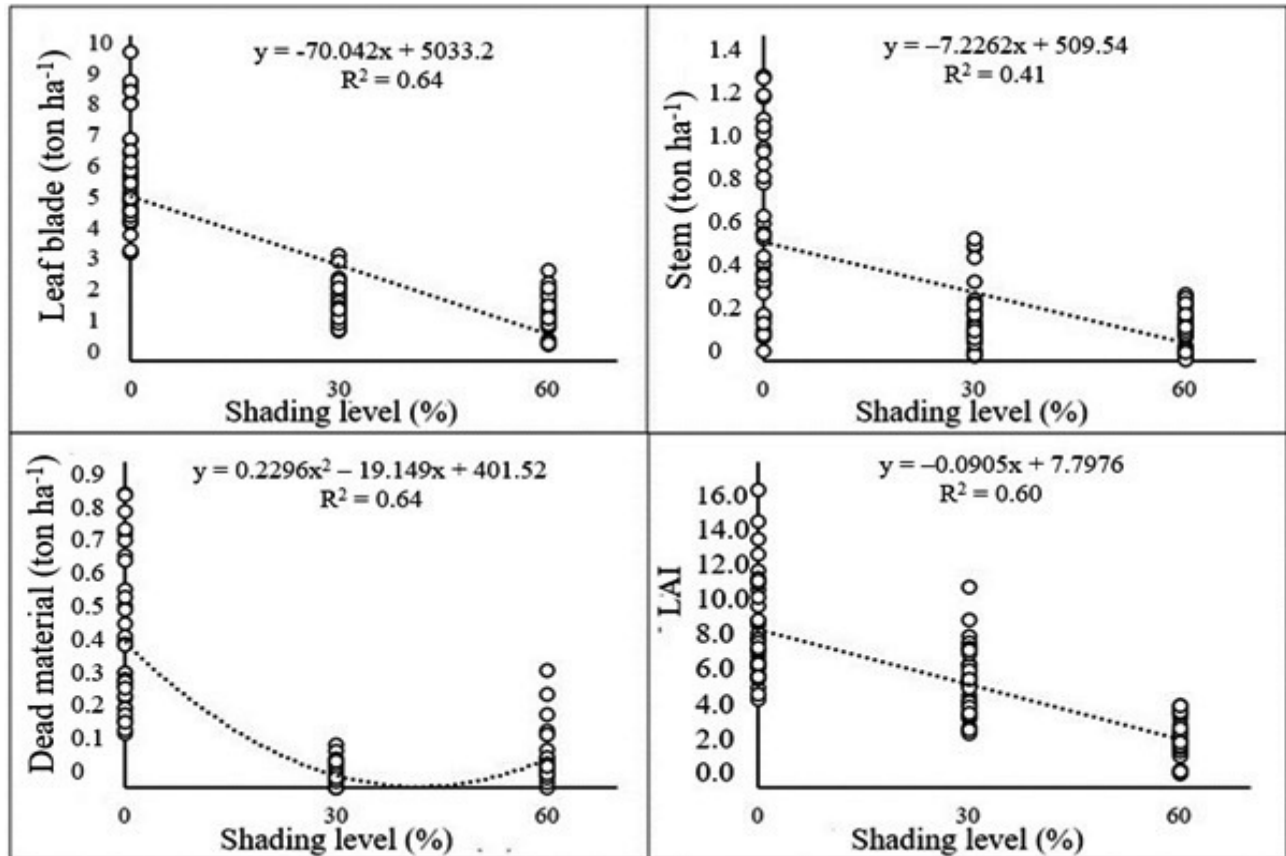


Figure 3: Morphologic components and leaf area index of Mombaça grass grown under three shading levels in Araguaína – Tocantins.

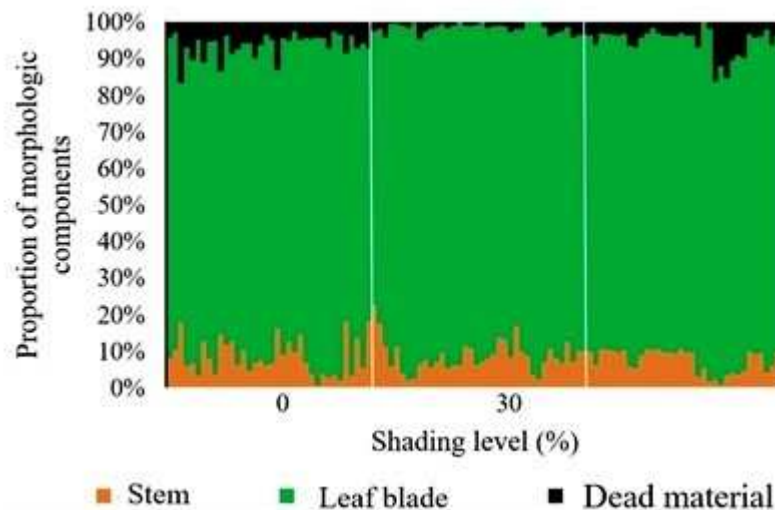


Figure 4: Proportion of morphologic components of Mombaça grass grown under three shading levels in Araguaína – Tocantins.

DISCUSSION

The effectiveness of the defoliation management of Mombaça grass in this study was shown by the lack of influence of the shading levels on the height of the grass canopy (Figure 1), which was carried out in accordance with the recommended management target of 90 cm (Silveira *et al.*, 2017) in the different environments analyzed, therefore, the agronomic and structural characteristics of Mombaça grass pasture were not influenced by the effect of canopy height (Oliveira *et al.*, 2020).

The lowest forage yield was obtained in the environment with the greatest shading level (60%), and the difference in comparison to the environments with 30% shading and no shade is mainly due to the difference in light intensity reaching the understory and not related to other climatic elements such as temperature and rainfall. Forage yield values observed in the present study are close to those found by other authors (Rodrigues *et al.*, 2016; Silva Neto *et al.*, 2015). However, they are lower than those found in traditional production systems, where there is no tree component (Dim *et al.*, 2015; Rodrigues *et al.*, 2016; Melo *et al.*, 2015). This shows that the reduction of light reaching the plants has a direct effect on forage performance, and consequently, in the bioeconomic viability of the agroforestry system.

Therefore, the success of forage production in agroforestry systems is mainly determined by the level of shading caused by the trees, which makes it difficult for photosynthetically active radiation (400 to 700 nm) to reach the understory (Belesky, 2005), and reduces the ratio red : distant red (Assuero and Tognetti, 2010), thus limiting the photosynthetic rates of the grasses (Gomes *et al.*, 2019) and consequently affecting tillering and pasture productivity (Santos *et al.*, 2016). For this reason, planning the spatial arrangement of the tree component when installing the system should allow for balanced interaction between the tree and forage components, optimizing production (Vieira Junior *et al.*, 2022).

In a previous study conducted in the same experimental area, Santos *et al.* (2016) found that in the first year of silvopastoral system implementation, the forage yield of 1.4 ton ha⁻¹ DM was considered low, and was attributed to low tillering caused by light restriction, with a 51.9% reduction in the tiller population when compared with the non-shaded environment, as well as to the fact that the area had not reached complete stabilization. Therefore, more time is needed for the Mombaça grass to adjust to environmental variations occurring in the agroforestry system, which could already be seen in the data from the present study, where forage yield in the same area was significantly higher. However, the increase was mainly due to individual gains and not to the increased tillering over the years. It is therefore believed that, in the long term, agropastoral systems can

overcome reductions in tiller density if the leaf area increases to maintain forage productivity (Gomes *et al.*, 2020).

However, tiller population density was strongly affected by the shading level, with no effect on tiller mass (Figure 2). This shows that the shading level increase in the agroforestry system compromises the tiller community, which influences the emergence of new tillers to prioritize the existing ones, mainly due to the reduction in the production of photoassimilates, compromising plant regeneration, growth and increase in tiller population (Silveira Junior *et al.*, 2017). In this case, the management of the frequency/intensity of defoliation should be moderate to reduce the impact on growth structures of the grass, mainly on the residual leaf area after defoliation, to ensure the sustainability of the integrated system (Pedreira *et al.*, 2017).

Paciullo *et al.* (2008) studied the morphological, structural and productivity characteristics of *Brachiaria decumbens* grass under different levels of shading (0, 18 and 50% shading) and also found reduction in the tiller population due to increased shading, which highlights the importance of light in the emergence of new tillers, with compensation by the plant by increasing the elongation rates and final length of the leaves, thus providing an increase in production per area and total production of 8.14% in the treatment subjected to 50% shading in comparison to no shade.

In addition, leaves that develop in environments without light restriction show greater photosynthetic efficiency when compared with those in shaded environments (Hodgson, 1990). Changes in tillering induced by the effect of shading, have also been reported by other authors (Lopes *et al.*, 2017; Oliveira *et al.*, 2020). This corroborates Paciullo *et al.* (2007), who state that tiller density is one of the main structural components of the canopy that is strongly influenced by light restriction and that affects forage yield.

Another important aspect of the possible causes for the reduction in tillering, in addition to the effect of light restriction, may be related to the pasture harvest strategy, when the height criterion (90 cm, rest period close to 27 days) was used to harvest the forage. The grass managed in silvopastoral system was probably penalized, as it needed more time to recover its organic reserves, which resulted in a continuous decrease in tiller population, with frequent harvests. Therefore, further studies should be conducted to test this hypothesis.

Analyzing the forage volumetric density, it is possible to better understand the vertical parameters of the pasture and the horizontal parameters of the forage canopy, as well as the interaction between tillers and their dependence on resources such as nutrients and light (Santos *et al.*, 2009). In the present study, higher volumetric forage density was observed under full sun exposure conditions (0% shading) when compared

with the SPS system, with significant reductions as light levels increased (Figure 2).

Forage volumetric density is directly correlated with the number of tillers (Belesky *et al.*, 2011), reinforcing the idea that tillering is one of the main contributors to the reduction in productivity of pastures maintained in silvopastoral systems, and aggravated by intense shading (60% shading). Reductions in the forage volumetric density have been found in other studies with *B. decumbens* maintained under three levels of shading (0, 20 and 70%) (Lopes *et al.*, 2017). On the other hand, parameters related to forage intake behavior by grazing animals, such as forage intake and bite size, can be compromised under conditions of reductions in the volumetric density of forage (Fontes *et al.*, 2014), which can limit animal production in agroforestry systems.

The use of nitrogen fertilization is one of the management strategies that influences the persistence and emergence of new tillers (Gomide *et al.*, 2007). In the quest to minimize the impact of shading on forage yield of *Megathyrsus maximus*, Paciullo *et al.* (2017) showed that increasing nitrogen availability via fertilization under moderate shading conditions (37% shading) improves the growth of existing tillers, which may be enough to promote a satisfactory accumulation of dry matter, contributing to maintain positive carbon balance and maximize growth under shading. Pereira *et al.* (2021) studied the anatomic and nutritional characteristics of genotypes of *Megathyrsus maximus* in silvo-pastoral system, and found a reduction in forage yield, but with better nutritional value in terms of tissue proportions and chemical composition than grasses grown under full sun. Therefore, nitrogen fertilization can be a management strategy used to optimize forage yield in shaded environments at moderate shading levels.

LAI decreased linearly with the progressive increase in shading (Figure 3). These values corroborate the results obtained in other studies (Gobbi *et al.*, 2009; Paciullo *et al.*, 2007). Under shaded conditions, plants can develop compensatory morphological mechanisms, such as increase in specific leaf area and leaf area ratio to capture photosynthetic active radiation, but, as a result of reductions in tiller population density (Figure 2), and consequently, in LAI, when compared with the cultivation under full sun exposure, to ensure survival of the challenge imposed. It is worth noting that the LAI of grasses is a result of tiller population density and leaf area per tiller (Reis *et al.*, 2013), explaining reductions in this index under shaded conditions. It therefore highlights the importance of managing tree density through pruning and thinning to maintain the productivity and longevity of Mombaça grass in agropastoral systems.

The morphological components of the biomass of Mombaça grass were influenced by the different levels of shading (Figure 3). The proportion of leaf blade increased in all shading levels (Figure 4), with no effect

on the leaf:stem ratio ($p > 0.05$). These results indicate that these morphophysiological changes are a compensatory adjustment by the plants to the reduction in tiller density. Belesky (2005) assessed the allocation of dry matter in *Dactylis glomerata* established in a silvopastoral system and found that under these conditions the plant increased the allocation of resources to leaf production when subjected to defoliation and light restriction. At the same time, there was increase in the plant's specific leaf area and leaf area ratio, which are fundamental characteristics for maintaining forage growth and improve light capture efficiency (Dias Filho, 2000).

Although there were reductions in forage yield in the shaded environments (Figure 1), lower levels of dead material were found under moderate shading levels (30% shading) (Figure 4). This shows the possibility of improvement in photosynthetic efficiency, resulting from the plant's morphophysiological adjustment to favor greater light capture, causing the plant to have a longer lifespan, with preference to the individual tiller rather than the tiller community, as a result of the attempt to conserve resources (photoassimilates) for the survival of the existing community (Santos *et al.*, 2016; Paciullo *et al.*, 2007).

On the other hand, the proportion of stem was not affected by the shading levels, while reductions in the proportion of dead material were observed at moderate shading levels (30% shading) (Figure 4). The absence of the effect of shading on the proportion of stem can be explained by the efficient monitoring of canopy height, aiming to harvest at the appropriate height, so there is no compensatory effect of light restriction in raising the height of the grass, to better capture light with increased shading (Paciullo *et al.*, 2017). This also shows that the harvest point of Mombaça grass was adequately met, using canopy height as the harvest criterion, since the proportion of stem and dead material were below the levels studied, in addition to providing greater plant efficiency in this condition, and favoring a longer leaf lifespan. Reich *et al.* (1991) found that Amazonian species adapted to shaded conditions during regeneration tend to produce thick, resistant and long-lived leaves, as mechanisms for prolonged leaf survival.

Therefore, from the nutritional point of view, there is a consensus in the literature that increasing the share of dead material and stem in the available forage is not desirable, as this morphological component is less digestible than leaves (Ball *et al.*, 2001; Reis *et al.*, 2013), in addition to influencing grazing behavior and animal intake (Van Soest, 1994). Thus, in the quest to optimize livestock systems in the Cerrado-Amazon ecotone, where pasture is the main focus compared with forest products of limited commercial value, agropastoral arrangements that provide 30% shading, accompanied by appropriate thinning and/or pruning management, and

efficient management of the intensity/frequency of defoliation are recommended, thus contributing to the improvement of pasture systems.

Conclusion: Increasing the shading level in Mombaça grass pastures had a direct effect on the production of tillers, which consequently resulted in a reduction in forage yield. Shading of around 60% in the agroforestry system, greatly reduced the tiller population density and forage volumetric density, as well as the LAI of Mombaça grass, when compared with conditions of 30% shading or no shading.

Therefore, Mombaça grass should be managed at a 30% shading level, which can be considered adequate to maximize forage yield, balancing the benefits of soil and water conservation with the possible negative impacts on forage yield.

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