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Nutrient absorption by Marandu grass subjected to shading levels and nitrogen doses in a silvopastoral system

Absorção de nutrientes pelo capim-marandu submetido a níveis de sombreamento e doses de nitrogênio em sistema silvipastoril

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Highlights

Minerals of Marandu grass subjected to levels of shading and nitrogen doses.
Shading did not affect the dry mass production of Marandu grass.
Nutrient levels increased with shading and nitrogen fertilization.

Abstract

The objective was to evaluate nutrient absorption in Marandu grass influenced by levels of eucalyptus shading in a silvopastoral system (SSP) and N doses, during two years of cultivation. The experimental design adopted was randomized blocks, with four replications. The experiment was conducted in a 3 x 7 factorial arrangement, corresponding to three nitrogen doses (0, 100, and 200 kg ha^{-1} $year^{-1}$ in the form of ammonium sulfate), six shading intensities of Marandu grass in SSP (SSP 40-45, SSP 35-40, SSP 30-

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35, SSP 25-30, SSP 20-25, SSP 15-20%), and one treatment with Marandu grass cultivated in full sun (monoculture). Chemical analyzes were performed to obtain macro and micronutrient concentrations in the Marandu grass material. The adoption of the integrated SSP system and N doses showed interaction (P <0.05) for phosphorus (P), potassium (K), and sulfur (S) levels in Marandu grass. Shading does not affect the dry mass production of Marandu grass. The increase in N doses and shading in the SSP favor the levels of phosphorus, potassium, sulfur, nitrogen, calcium, magnesium, iron, zinc, copper, manganese and boron in Marandu grass, compared to full sun. The presence of 40-45% shade provides the highest levels, demonstrating greater benefits for forage quality in SSPs compared to monoculture pastures.
Key words: Tropical forage. Livestock-forest integration. Agroforestry systems. *Urochloa brizantha.*

Resumo

Objetivou-se avaliar a absorção de nutrientes em capim-maradu influenciada por níveis de sombreamento do eucalipto num sistema silvipastoril (SSP) e doses de N, durante dois anos de cultivo. O delineamento experimental adotado foi em blocos casualizados, com quatro repetições. O experimento foi conduzido em arranjo fatorial 3 x 7, correspondendo a três doses de nitrogênio (0, 100 e 200 kg ha^{-1} ano^{-1} na forma sulfato de amônio), seis intensidades de sombreamento do capim-marandu nos SSP(SSP 40-45, SSP 35-40, SSP 30-35, SSP 25-30, SSP 20-25, SSP 15-20 %), e um tratamento com capim-marandu cultivado a pleno sol (monocultivo). Foram realizadas análises químicas para obter-se as concentrações de macro e micronutrientes no material vegetal do capim-marandu. A adoção do sistema integrado SSP e as doses de N apresentaram interação (P<0,05) para as os teores de fósforo (P), potássio (K) e enxofre (S) no capim-maradu. O sombreamento não afeta a produção de massa seca do capim-marandu. O aumento das doses de N e o sombreamento no SSP favorecem os teores de fósforo, potássio, enxofre, nitrogênio, cálcio, magnésio, ferro, zinco, cobre, manganês e boro no capim Marandu, em comparação ao pleno sol. A presença de 40-45% de sombra proporciona os maiores teores, demonstrando maiores benefícios para a qualidade da forragem nos SSPs em comparação às pastagens em monocultivo.
Palavras-chave: Forrageira tropical. Integração pecuária-floresta. Sistemas agroflorestais. *Urochloa brizantha.*

Introduction

The search for agricultural production systems that are efficient, sustainable, and ecologically balanced has led to the increasing adoption of silvopastoral systems (Chará et al., 2019). This integrated approach combines tree cultivation with animal husbandry and forage production, providing a range of benefits, both environmental and economic (Jose et al., 2019). The forage species Marandu grass (*Urochloa brizantha* (Hochst. ex A.Rich.) RD Webster; syn. *Urochloa brizantha* (A.Rich.) Stapf) is considered a promising candidate for integrating silvopastoral systems, as it is one of the main forage grasses used in tropical pasture systems (Bezerra et al., 2020). However, the nutritional quality of this grass may be influenced by environmental factors, such as shading and nutrient availability, especially nitrogen.

Shading in silvopastoral systems, resulting from the presence of trees, alters the microenvironmental conditions of pastures, affecting light availability, temperature, and humidity. However, plants show potential for acclimation to variable light conditions among species, as some may increase their photosynthetic capacity when transferred from high to low irradiance, according to morphophysiological plasticity (Shomali et al., 2024). These environmental changes impact the mineral composition of forage plants and the nutrition of the animals that feed on them (Collet et al., 2018). Additionally, nitrogen fertilization is often used to improve pasture yield and quality, but the combined effects of shading and nitrogen addition on mineral levels of Marandu grass in silvopastoral systems have not been adequately explored.

This study was proposed to fill this knowledge gap, focusing on the evaluation of mineral levels in Marandu grass when subjected to different shading levels in combination with nitrogen doses. Previous research highlights the importance of the interaction between shading production and forage quality in silvopastoral systems (Varella et al., 2016). Other studies (Paciullo et al., 2017; Lopes et al., 2017; Rodrigues et al., 2019) also demonstrated that light management and nutrient supplementation directly affect mineral concentration, implicating plant performance and, subsequently, of the animals that consume them. However, specific studies on mineral levels in marandu grass in silvopastoral systems are limited, making this investigation essential. Understanding the factors that influence the availability of these nutrients is essential to formulate accurate recommendations on the amount of minerals needed to effectively meet the needs of animals.

Furthermore, considering the context of silvopastoral systems, where the interaction between trees, forage, and animals plays a crucial role, the results of this study will contribute to scientific knowledge about the nutrition of forage plants in shaded environments, offering valuable insights to optimize livestock production in tropical systems.

Thus, the objective was to evaluate nutrient absorption in Marandu grass influenced by shading intensities and N doses in a silvopastoral system (SSP) with eucalyptus, during two years of evaluation.

Materials and Methods

Study area

The study was conducted in an experimental area with a silvopastoral system (SSP) established at the Experimental Farm of Moura (FEM), belonging to the Federal University of Vale do Jequitinhonha and Mucuri (UFVJM). The FEM is located in Curvelo, Minas Gerais, Brazil, at coordinates 18°44'52.03" S and 44°26'53.56" W.

The region's climate, according to the Köppen and Geiger (1948), is a tropical savanna type, with a well-defined dry season (autumn-winter) and rainy season (spring-summer), with an average annual precipitation of 1074.5 mm and an average annual temperature of 22.9°C (Instituto Nacional de Meteorologia [INMET], 2024) (Figure 1).

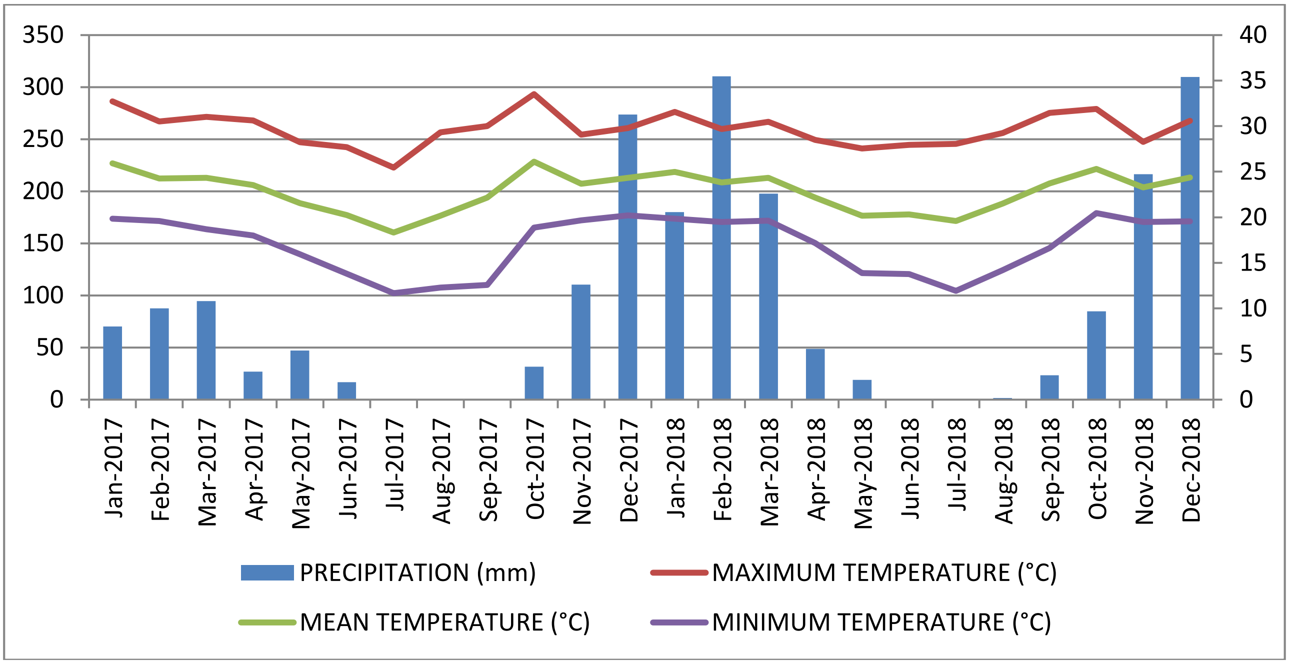

Figure 1. Climatic data recorded during the experimental period, from January 1, 2017, to December 31, 2018 - Curvelo, MG.

Soil physical and chemical analyses were performed in the 0-20 cm layer. After analysis, the soil was classified as Red Latosol, with clayey texture, presenting the following chemical characteristics: pH in H_2O = 5.9; P = 1.03 mg dm^{-3}; K = 146.33 mg dm^{-3}; Ca^{2+} = 4.75 cmolc dm^{-3}; Mg^{2+} = 0.76 cmolc dm^{-3}; Al^{3+} = 0.1 cmolc dm^{-3}; H+Al = 4.23 cmolc dm^{-3}; SB = 3.97 cmolc dm^{-3}; t = 4.07 cmolc dm^{-3}; T = 8.26 cmolc dm^{-3}; V = 47.66%; m = 4%; OM = 3.92 dag kg^{-1}; P-rem = 13 mg L^{-1}; Zn = 0.67 mg dm^{-3}; Fe = 39.3 mg dm^{-3}; Mn = 59.56 mg dm^{-3}; Cu = 1.3 mg dm^{-3}; B = 0.1 mg dm^{-3}.

The SSP was established in 2014 with clonal eucalyptus trees (clone I144, hybrid between Eucalyptus urophylla x Eucalyptus grandis). Planting holes of 40×40×40 cm were prepared, and planting fertilization included 0.200 kg of reactive natural phosphate and 0.125 kg of N-P_2O_5-K_2O (8-28-16) formulation per hole, mixed into the soil before transplanting the seedlings. Transplanting of eucalyptus seedlings to the field was done with 1.5 m spacing between the forage and eucalyptus rows. Sixty days after transplanting, a maintenance fertilization was performed with 0.125 kg of potassium chloride, 0.05 kg of ammonium sulfate, 0.010 kg of borax, and 0.005 kg of zinc sulfate per hole.

Eucalyptus plants were grown in single rows spaced 12 × 2 m and 12 × 3 m in silvopastoral systems, and Marandu grass in monoculture. The experimental units of the consortium treatments had dimensions of 36 m width by 18 m length, totaling an area of 648 m^2, composed of four single eucalyptus rows spaced every 12 m, interspersed with the forage species. For the Marandu grass monoculture areas, the dimensions were 10 m wide by 108 m long, totaling 1,080 m^2, divided into three experimental units 10 m wide by 36 m long, totaling 360 m².

Marandu grass pasture [*Urochloa brizantha* (Hochst. ex A. Rich.) R. Webster cv Marandu] was established in the tree row spaces in 2015, at the same time as the tree planting. Seeding fertilization used was 400 kg ha^{-1} of N-P_2O_5-K_2O (8-28-16) formulation. The seeds of the forage specie were added and homogenized with the fertilizer and distributed with a spacing of 0.40 m. In this case, the interval between mixing the seeds to fertilizer was less than six hours, to avoid loss of seed germination power due to the saline effect of fertilizer. For all treatments, 4 kg ha^{-1} of pure viable seeds were used. Between establishment and the beginning of this study, the forage was grazed by dairy cattle under continuous stocking with no specific forage height and fertilization management.

The start of the experimental period was marked by uniform cutting of Marandu grass plants 0.2 m above ground level, performed with a brush cutter (Stihl, São Leopoldo, Brazil). Following mowing, nitrogen fertilization of forages in the form of ammonium sulfate was carried out in the quantity necessary to provide the nitrogen doses that constituted one of the study factors (0, 100, and 200 kg ha^{-1} $year^{-1}$). It is worth noting that during the experimental period, there was no animal entry and grazing, with cuts made using a brush cutter, and the material removed from the experimental plots, simulating grazing by cattle.

Experimental design and treatments

The experiment was conducted in a 3 x 7 factorial design, corresponding to three nitrogen doses (0, 100, and 200 kg ha^{-1} $year^{-1}$ as ammonium sulfate), six shading intensities of Marandu grass in the silvopastoral system (SSP 40-45, SSP 35-40, SSP 30-35, SSP 25-30, SSP 20-25, SSP 15-20%); and one treatment with Marandu grass grown in full sunlight (monoculture); distributed in a randomized complete block design, with four replications (Figure 1). The evaluations were repeated over two years of cultivation.

To determine the shading intensities imposed by the eucalyptus trees, the average percentage reduction of photosynthetically active radiation (PAR, μmol m^{-2} s^{-1}) incident above and below the canopies was evaluated. The AccuPar LP-80 Ceptometer device was used for these measurements. Five measurements of light interception were taken at points arranged within each planting arrangement (monoculture; full sunlight), in the eucalyptus interline, and at distances of 2, 4, and 6 m), with calculations performed in relation to plants grown in full sunlight.

Measurements and laboratory analyses

The assessments were repeated over two years of Marandu grass cultivation, the period in which the research was carried out. The plants were cut when the marandu grass pastures reached 95% light interception (LI) to assess forage production and subsequently verify mineral concentrations by the *U. brizantha* cultivar under different grazing management.

Two points per experimental unit were randomly sampled using a polyethylene square with an area of 0.50 m^2, at distances of 2, 4, and 6 m from the eucalyptus row on each side, aiming for sample representativeness. For monoculture marandu grass plants, random collections were made at six different points in each experimental unit, using squares of the same size (Figure 2). All plants from the squares were cut 20 cm above ground level. After harvesting, samples of the aboveground parts of the forage plants were placed in identified plastic bags and taken to the laboratory, where they were weighed, placed in kraft paper bags, placed in a forced air ventilation oven at 55°C for 72 hours or until constant weight, and subsequently ground in a Wiley mill with a 1mm mesh sieve.

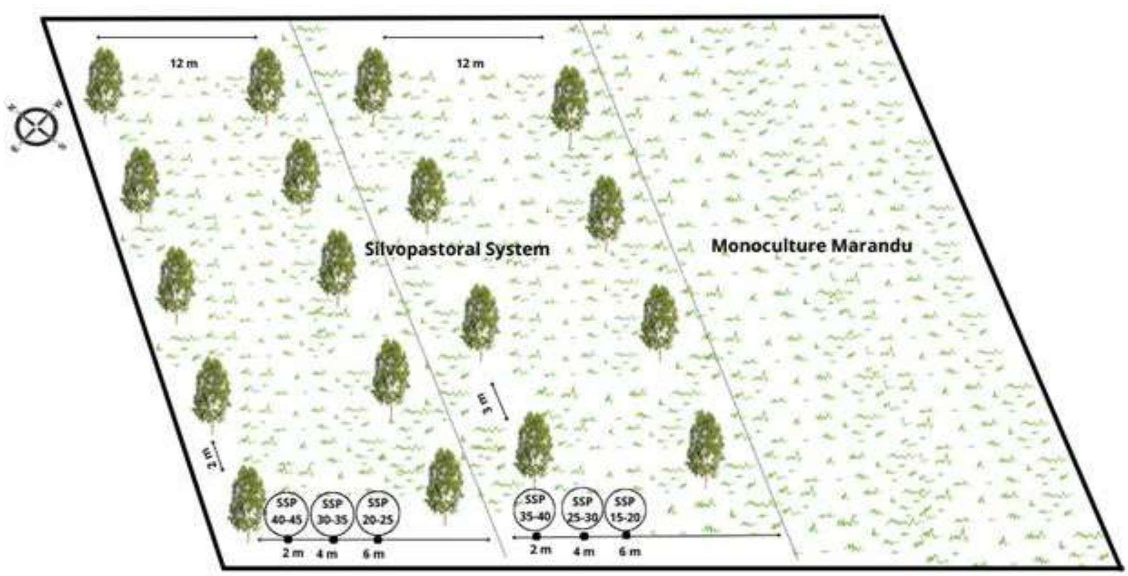

Figure 2. Illustrative figure with schematic representation of light availability in the silvopastoral system (SSP) with sampling locations (between rows; 2, 4, and 6 m to the north and south) and monoculture pasture (full sun).

After sample preparation, acid digestion of the samples was performed to extract marandu grass aerial part material (Tedesco et al., 1995). Nitrogen determination was done by the Kjeldahl method, after sulfuric acid digestion. Determinations of other nutrients were carried out after nitric-perchloric digestion. Phosphorus (P) concentration was obtained by colorimetry using the metavanadate method, while Ca, Mg, Cu, Fe, Mn, Zn, and B were determined by atomic absorption spectroscopy, K by flame photometry, and S by the turbidimetric method.

Statistical analyses

The data were subjected to analysis of variance (ANOVA) at a 5% significance level, evaluating the effects of shading × nitrogen doses and the interaction between factors. When interactions were significant, post hoc tests were conducted, and when there was no significance, factors were analyzed separately. Mean comparisons were performed using Tukey's test at a 5% significance level. All statistical analyses were conducted using the statistical software SAEG version 9.1. (SAEG, 2007).

Results and Discussion

The adoption of the integrated SSP system and N doses showed interaction ($P < 0.05$) for the phosphorus (P), potassium (K), and sulfur (S) content in Marandu grass (Table 1).

Higher shading levels resulted in increased P content in plants, regardless of the N doses added to the soil (Table 1). This can be attributed to the reduced growth and biomass production commonly observed in shaded plants, leading to a higher concentration of this nutrient in the plant. However, the present study indicates that Marandu grass did not experience changes in dry mass production at any of the light intensities imposed by the SSP (Table 2). On the other hand, increasing N doses promoted P absorption by Marandu grass in monoculture and shaded plants in the SSPs, which can be explained by the relationship between these two minerals. Nitrogen stimulates both shoot and root growth; increased root growth may facilitate P absorption, which moves in the soil by diffusion. This increase in P absorption occurred starting at the application of 100 kg ha^{-1} $year^{-1}$ of N and was lower in monoculture and in the SSP with 15 to 20% shading, suggesting that the shading levels of the SSP exert greater influence on the concentration of this mineral in relation to the evaluated N doses. According to Hanisch et al. (2016), the increase in P in shaded systems can be attributed to intensified mobilization of this element in the soil, resulting from increased microbiota activity, enhancing its availability. The increase in soil organic matter composition in naturally shaded environments also has a positive impact on the dynamics of nutrients available to plants, contributing to absorption and consequently increasing P concentrations in plant structure (Zhang et al., 2021). The higher concentration of phosphorus in plants influences the nutritional quality of available forage for cattle, and this increase is directly associated with forage mass produced. Phosphorus is an essential nutrient in the animal diet, necessary for functions such as bone formation, reproduction, energy metabolism, energy transfer (ATP) within cells, and also has significant importance in rumen microorganism activity (F. V. Rezende et al., 2019). The increase in P concentrations in plant structure can reduce the need for additional supplementation in the trough. This can lead to significant savings in terms of feeding and management costs, as well as reducing environmental impact.

Similar results to those obtained for P were also found for potassium (K) contents, where at all N doses studied, shading of SSP 40-45 was superior in K concentration in Marandu grass plants compared to other treatments (Table 1), reinforcing the effect of the SSP. Furthermore, when analyzing the influence of N doses on plant K content, it was observed that there was an increase in the absorption of this macronutrient when nitrogen fertilization was applied (100 and 200 kg ha^{-1} $year^{-1}$), which is justified by the fact that K in the soil, unlike P, had a good content. Therefore, if the plant has better growth conditions due to nitrogen fertilization, it will absorb more K.

Table 1
Average levels of phosphorus (P), potassium (K) and sulfur (S) in Marandu grass subjected to nitrogen doses and shading levels with eucalyptus in silvopastoral system (SSP) and monoculture, during two years of cultivation

Shade cultivation systems (%)	Dose 0	Dose 100	Dose 200	Mean	Dose 0	Dose 100	Dose 200	Mean	Dose 0	Dose 100	Dose 200	Mean
Monoculture (0)	1,91Ec	2,08Db	2,17Fa	2,05	11,76Eb	12,65Eb	15,63Ea	13,35	1,54Ec	1,76Eb	1,90Ea	1,73
SSP (15-20)	2,07Dc	2,14Db	2,25EFa	2,15	12,08Ec	14,24Db	16,81Ea	14,38	1,75Dc	1,86Db	1,98DEa	1,86
SSP (20-25)	2,24Cb	2,28Cab	2,31DEa	2,28	13,08DEc	15,01Db	19,80Da	15,96	1,96Cb	2,01Cab	2,04CDa	2,00
SSP (25-30)	2,27BCa	2,31BCa	2,34CDa	2,31	13,55CDc	15,46CDb	21,26Ca	16,76	2,01BCb	2,06BCab	2,08Ca	2,05
SSP (30-35)	2,30ABCb	2,33BCb	2,40BCa	2,34	14,69BCc	16,50BCb	23,04Ba	18,08	2,04BCb	2,08BCab	2,13BCa	2,08
SSP (35-40)	2,34ABb	2,37ABb	2,44ABa	2,38	15,55ABc	17,86Bb	23,27Ba	18,89	2,09ABb	2,14ABab	2,21ABa	2,15
SSP (40-45)	2,38Ab	2,44Aab	2,49Aa	2,44	16,45Ac	19,70Ab	26,04Aa	20,73	2,14Ab	2,21Aa	2,27Aa	2,21
Mean	2,22	2,28	2,34		13,88	15,92	20,84		1,93	2,02	2,09	
CV (%)		1,71				3,87				2,17		

* Means followed by the same letter do not differ statistically from each other, uppercase in the column and lowercase in the row, according to the Tukey test at 5% probability.

With increasing shading in the SSP and increasing N doses, there was an increase in K content in the plants. Based on the results, there was a high concentration of K in the forage compared to other minerals. A higher K content was verified compared to N, corroborating with the work of Costa et al. (2010), which states that the K content by Urochloa brizantha is generally higher than the amount of N, as also found in this study.

The potassium has high mobility, translocating from older to newer tissues via xylem and phloem (Melo et al., 2018), and it acts in various vital physiological reactions in plants, and low availability of macronutrients such as K and P can reduce seed production in plants (Godoy et al., 2022). There is a significant demand for this nutrient for the maintenance of the animal organism, since K plays a crucial role as the main cation of intracellular fluid. Through its interactions with sodium, chlorine, and bicarbonate ions, together they play a prominent role in osmotic pressure regulation, acid-base balance, nerve impulse conduction, and muscle excitability. In the rumen environment, potassium is closely related to preserving action and maintaining moisture levels (Pissinati et al., 2018). Adequate availability of this mineral improves the nutritional quality of forage, increasing protein content, digestibility, and overall nutritional value. This has a direct impact on the health and performance of animals consuming this forage.

Regardless of the evaluated nitrogen dose (0, 100, or 200 kg ha-1 year-1), the shading level of SSP 40-45 was the one that showed the highest sulfur (S) plant content by Marandu grass plants compared to monoculture (Table 1). Marandu grass managed in monoculture and in SSP with 15-20% shading was more influenced by the N doses applied when compared to the effect exerted by the evaluated shadings. The higher the shading levels, the more the effect caused by N doses was diluted, and the effect of shading was evident. However, it is important to note that the addition of NH3 during nitrogen fertilization resulted in higher S concentrations, as the fertilizer amount was increased, consequently increasing the S content. It is worth mentioning that nitrogen fertilization is directly related to plant performance; however, in this study, it is the shading obtained through SSP that exerts a greater influence on the S content. Similar results were verified by L. F. M. Santos et al. (2020) in S contents by Marandu grass evaluating the availability and demand of the culture. S deficiency in the animal diet can lead to health problems, such as growth delay, brittle hooves, and skin problems (Almeida et al., 2023). Therefore, understanding the relevance of sulfur in the animal diet is essential to ensure the health and proper performance of animals in silvopastoral systems and other animal production systems.

There was no significant interaction (P> 0.05) between N doses and shading for dry mass production (DMP), nitrogen (N), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), and boron (B) (Table 2), however, there was an isolated effect of different shading levels. No shading effect was observed for dry mass production (DMP) of Marandu grass.

The results indicate that shading from SSP provided dry mass production (DMP) similar to monoculture (Tables 2), highlighting a positive effect of shading by not reducing production. This demonstrates Marandu grass's tolerance to reduced light availability imposed by SSPs, not affecting forage productivity.

The forage produced in the silvopastoral systems SSP 40-45 shading showed a 24% increase in nitrogen (N) content in its tissue compared to monoculture (Table 2), which was also observed by P. R. Rezende et al. (2022) and Lopes et al. (2017). These results suggest that shading can play a fundamental role in increasing nitrogen absorption by Marandu grass. Contrary to morphological changes that some species may develop under shading conditions, such as larger leaves to capture more available light (Zhang et al., 2021; M. V. Santos et al., 2018). These changes can influence the rate of photosynthesis and thus indirectly affect nitrogen absorption (Wang et al., 2023). Additionally, this increase may be attributed to higher organic nitrogen mineralization in the soil, in the nutrient cycling process (Paciullo et al., 2011; Araújo et al., 2016). In this study, Marandu grass showed a positive response regarding plant nitrogen levels in shaded systems.

Table 2

Dry mass production (DMP) and average levels of nitrogen (N), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), and boron (B) in Marandu grass subjected to shading levels with eucalyptus in silvopastoral system (SSP) and monoculture, during two years of cultivation

Shade cultivation systems (%)	DMP (t ha^{-1})	N (g kg^{-1})*	Ca (g kg^{-1})*	Mn (mg kg^{-1})*	B (mg kg^{-1})*	Mg (g kg^{-1})*	Zn (mg kg^{-1})*	Fe (mg kg^{-1})*	Cu (mg kg^{-1})*
Monoculture (0)	26203,77a	1,05d	11,77b	121,38b	14,12b	3,57c	21,34c	133,75b	8,62b
SSP (15-20)	22346,33a	1,13cd	12,48ab	125,78ab	14,49ab	3,66bc	22,61bc	135,42ab	8,95ab
SSP (20-25)	22448,22a	1,13cd	12,39ab	125,82ab	14,45ab	3,71bc	23,06abc	136,59ab	8,86ab
SSP (25-30)	22636,92a	1,18c	12,70ab	127,00a	14,66ab	3,74abc	23,68ab	137,08ab	9,08ab
SSP (30-35)	21020,92a	1,21bc	12,88a	128,36a	14,73a	3,83ab	23,94ab	137,47ab	9,16ab
SSP (35-40)	20044,50a	1,30ab	13,04a	128,74a	14,74a	3,84ab	24,17ab	138,43a	9,22ab
SSP (40-45)	20801,72a	1,38a	13,31a	129,60a	14,93a	3,94a	25,10a	139,89a	9,33a
Means	22214,62	1,20	12,66	126,67	14,59	3,76	23,41	136,95	9,03
CV (%)	24,46	7,49	6,81	3,32	3,30	4,97	7,76	2,65	5,78

* Means followed by different letters differ statistically from each other, according to Tukey's test at a 5% probability level.

Plant shading also increased calcium (Ca), manganese (Mn), and boron (B) levels in Marandu grass (Table 2), with the highest extractions observed in SSP 40-45, SSP 35-40, and SSP 30-35 shadings and the lowest extractions in monoculture. Côrt et al. (2021) evaluating the nutrient utilization efficiency by Urochloa ruziziensis in no-till cultivation systems found higher calcium accumulation compared to monoculture, highlighting the benefits of organic matter present in both systems.

The calcium is one of the main components involved in the formation of plant cell walls and cell elongation. Well-formed cell walls can influence the ability to break down cellulose and other complex plant components in the animal digestive system, making forage more easily digestible (Marschner, 2012). The higher Mn plant content in SSPs is justified by the greater absorption of Mn being given by mass flow and thus dependent on water in the soil solution; given that these systems retain more moisture (Barber, 1962).

The manganese levels below 200 mg kg^{-1} hardly cause toxicity problems in cattle (National Research Council [NRC], 2021), which goes against the results found in this study. On the other hand, B acts on apical meristems and contributes to better performance in forage dry mass production (Andrade et al., 2019). SSPs favored the concentration of this mineral, which can be attributed to the adequate original content of the element in the soil and the supply of the micronutrient via organic matter; having mass flow as the predominant mechanism for B transport in the soil (Shomali et al., 2024). Although B is needed in very small amounts, it performs several essential functions in animal health and performance, including protein synthesis, sugar transport, respiration, RNA and carbohydrate metabolism (Shomali et al., 2024).

As for magnesium (Mg) mineral contents, these behaved similarly to zinc (Zn), with higher concentrations of these minerals in Marandu grass managed in shading from SSP 40-45 to SPP 20-25 (Table 2). The influence of shading on Mg levels in Marandu grass may vary based on several factors, including the duration and intensity of shading, as well as specific soil conditions. Mg is an essential component of chlorophyll, the molecule responsible for photosynthesis; therefore, variations in light exposure can influence the absorption and utilization of this nutrient by the plant. Under shading conditions, the rate of photosynthesis may be reduced, which could indirectly impact Mg levels. However, it is important to note that results may vary based on morphological adaptation changes of forage plants, management practices, and other environmental factors. These results corroborate with those obtained by Castro et al. (2001), who found a higher Mg content in *Urochloa brizantha* leaves due to the presence of this element in chlorophyll molecules, increased in leaves under reduced luminosity. This increase in plant Mg content in SSPs benefits the system in that the adequate concentration of magnesium contributes to forage production with higher protein and carbohydrate content, resulting in forage richer in nutrients for animals (Galindo et al., 2019).

The magnesium plays a role in regulating the nervous system, muscle contraction, and cardiovascular function of animals, and the lack of this nutrient in the animal diet can lead to health problems, such as "grass tetany", characterized by a series of metabolic disorders and involuntary muscle contractions. Additionally, in the Southern Hemisphere, in countries like New Zealand, Australia, and Argentina, hypomagnesemia is one of the leading causes of death in grazing beef cattle. To address this problem, correct Mg supplementation is necessary (Doncel et al., 2021).

In SSP 40-45, the highest zinc (Zn) concentration was observed, highlighting the importance of shading compared to monoculture. Zn is an essential mineral in nutrition, acting as a cofactor for many enzymes involved in metabolism; it plays a crucial role in DNA, RNA, and protein synthesis, growth, reproductive health, and healthy animal development (NRC, 2021; Rotta et al., 2019). NRC (2021) recommends a zinc content of 40 mg kg^{-1} for beef cattle. Therefore, understanding the importance of zinc in animal nutrition is essential to promote the health and proper performance of animals in mixed systems.

For iron (Fe) and copper (Cu) mineral contents, there was a similar behavior in the plant contents of these minerals in Marandu grass, with the highest contents being observed in SSP 40-45 shadings compared to monoculture. The other systems did not differ from each other. Fe is essential in hemoglobin synthesis, energy metabolism, immune system, healthy development, and reproduction. Iron deficiency in animals can result in health problems, low productive and reproductive performance, and even mortality (Lana et al., 2020). Martins et al. (2020) reports on the importance of the micro-mineral Cu, highlighting the damage caused by deficiency and/or excess of this mineral in the animal organism; which can result in serious health problems, including anemia, skin and hair problems, low growth rate, reproductive problems, and compromised immunity.

In this study, only nitrogen doses showed an effect on Marandu grass DMP. It was observed that there was no significant difference between treatments without nitrogen fertilization and those fertilized with 100 kg ha^{-1} (Table 3). However, a significant difference was noted between treatments without fertilization and the application of 200 kg ha^{-1}, with treatments receiving this N dose showing a 68% increase in production. When evaluating treatments receiving fertilization of 100 kg ha^{-1} and 200 kg ha^{-1}, a significant difference was found between doses, with a 47% increase in Marandu grass DMP (Table 3). This increase in production is attributed to the importance of nitrogen in the growth of forage plants, being one of the main nutrients that most impact on increased productivity and improved quality (Taiz et al., 2017).

Table 3

Dry mass production (DMP) and mean levels of levels of nitrogen (N), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), and boron (B) in Marandu grass subjected to nitrogen doses in silvopastoral system (SSP) and monoculture, during two years of cultivation

Nitrogen doses (kg ha^{-1} year^{-1})	DMP (t ha^{-1})	N (g kg^{-1})*	Ca (g kg^{-1})*	Mg (g kg^{-1})*	Fe (mg kg^{-1})*	Zn (mg kg^{-1})*	Cu (mg kg^{-1})*	Mn (mg kg^{-1})*	B (mg kg^{-1})*
0	17385,79b	0,85c	10,17c	3,51c	103,89c	15,51c	7,81c	106,47c	13,53c
100	19939,03b	1,30b	12,95b	3,81b	145,20b	23,27b	9,08b	128,35b	14,60b
200	29319,06a	1,44a	14,84a	3,95a	161,75a	31,46a	10,20a	145,18a	15,64a
Means	22214,62	1,20	12,66	3,76	136,95	23,41	9,03	126,67	14,59
CV (%)	24,46	7,49	6,81	4,97	2,65	7,76	5,78	3,32	3,30

* Means followed by different letters differ statistically from each other, according to Tukey's test at a 5% probability.

Increasing nitrogen doses (100 and 200 kg^{-1}) favored the contents of N, Ca, Mg, Fe, Zn, Cu, Mn, and B in Marandu grass (Table 3). The development and productivity of crops, especially grasses, are significantly influenced by N, which is the most crucial nutrient. This mineral element is present in higher concentrations in vegetative tissues and plays a fundamental role in protein synthesis, chlorophyll, coenzymes, phytohormones, nucleic acids, and secondary metabolites. Additionally, N plays a crucial role in plant response to stress, disease resistance, and other adverse factors such as variation in light incidence (Galindo et al., 2019). Thus, the greater availability of N to Marandu grass may have benefited root system development, which, by exploring a larger soil volume, may have increased micronutrient and water absorption, reflecting the higher contents of N, Ca, Mg, Fe, Zn, Cu, Mn, and B found in Marandu grass.

Understanding the need for nitrogen fertilization to increase macro and micronutrient contents in Marandu grass is decisive for the system's greater efficiency. Macronutrient extractions were higher for Ca and Mg, followed by N, similar to extractions obtained by Carvalho et al. (2006), Primavesi et al. (2006), and Costa et al. (2010), and for micronutrients were higher for iron, manganese, zinc, boron, and copper, similar to extractions obtained by Braz et al. (2004). These same authors observed a positive effect on N application regarding the concentration of these minerals in Urochloa brizantha plants, demonstrating the efficiency of nitrogen fertilization.

The positive influence of shading on the mineral composition of Marandu grass contributed to richer and more balanced forage, which directly reflects on the herd's diet. Improving forage quality can reduce dependence on external nutritional supplementation, positively impacting operating costs. Therefore, by adopting integration with SSP as part of pasture management, not only animal welfare is promoted, but a sustainable practice is also established that benefits the efficiency of the agricultural system as a whole.

Conclusions

Shading does not impact the dry mass production of Marandu grass. However, nutrient levels increase with nitrogen fertilization. Plants grown in monoculture consistently exhibit lower mineral content compared to those in SSPs, regardless of the nitrogen dose applied. Marandu grass grown in silvopastoral systems ranging from 25-30% to 40-45% shading presents higher concentrations of macro and microminerals.

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