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Marandu grass under deferment in monoculture and silvopastoral system: chemical and mineral composition

Capim marandu sob diferimento em monocultivo e sistema silvipastoril: composição bromatológica e mineral

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Abstract: This study aimed to evaluate the chemical and mineral characteristics of Marandu grass under stockpiling in monoculture (MC) and a silvopastoral system (SPS) with 12- (SPS12) and 18-m (SPS18) spacing between tree rows. The experimental design consisted of randomized blocks, in which each system was allocated individually. Each treatment was formed in the center of each plot in a 3 × 4 factorial arrangement consisting of three systems (MC and SPS12 and SPS18 between the tree rows) and four stockpiling periods (60, 90, 120, and 150 days), totaling 12 treatments with three replications. No interaction effect was observed between the factors ($p>0.05$) for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), phosphorus (P), potassium (K), calcium (Ca), or magnesium (Mg). The CP content decreased with increasing stockpiling days but met the suggested requirement for ruminants up to 75 days. The NDF and ADF concentrations increased, while P and K contents decreased with increasing stockpiling days. Magnesium and Ca concentrations did not differ with stockpiling days. However, a difference was observed only for Mg relative to the evaluated systems, which was higher in MC and SPS12, differing from SPS18. The spacing adopted in the SPS of 12 and 18 m does not negatively influence the nutritional value of the forage plant. The 75-day stockpiling period from March favored the concentration of macronutrients and CP content in Marandu grass in both MC and SPS.

Keywords: diversified system; forage grass; macronutrients; protein; nutritional value; protein.

Resumo: O objetivo deste trabalho foi avaliar as características bromatológicas e minerais do capim Marandu sob diferimento em monocultivo (MC) e em sistema silvipastoril (SSP) com 12 (SSP12) e 18 m (SSP18). O delineamento experimental foi em blocos ao acaso, onde cada sistema foi alocado individualmente. No centro de cada parcela formou-se cada tratamento em fatorial de 3 x 4, composto por três sistemas (MC e SSP12 e SSP18 entre as fileiras das árvores) e quatro períodos de diferimento (60, 90, 120 e 150 dias), perfazendo doze tratamentos com três repetições.Não houve efeito de

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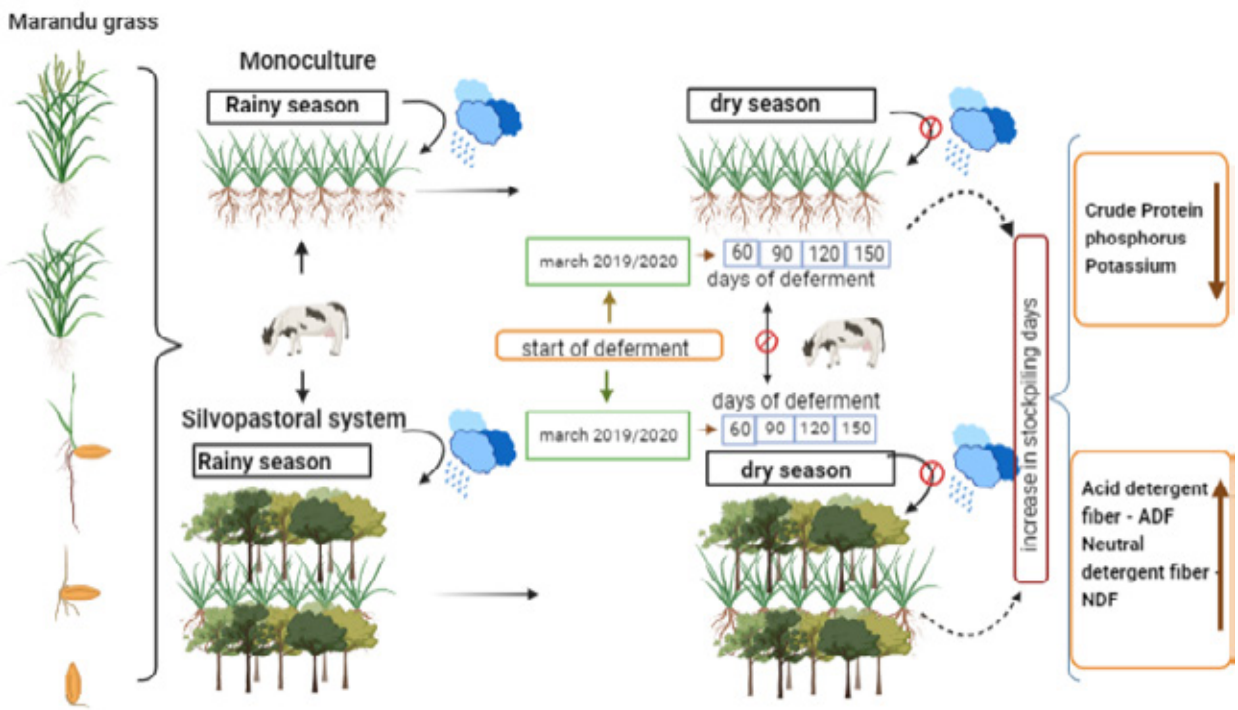
interação entre os fatores (p>0,05) para proteína bruta (PB), fibra em detergente ácido (FDA), fibra em detergente neutro (FDN), fósforo (P), potássio (K), cálcio (Ca) e magnésio (Mg). O teor de PB diminuiu com o incremento nos dias de diferimento, mas até os 75 dias atendeu a demanda sugerida para ruminantes. As concentrações de FDN e FDA aumentaram, enquanto os teores de P e K diminuíram com o incremento nos dias de diferimento. A concentração de Mg e Ca não diferiu com os dias de diferimento. No entanto, em relação aos sistemas avaliados houve diferença apenas para Mg, que foi maior em MC e SPS12, diferindo de SPS18. O espaçamento adotado no SSP de 12 e 18m não influencia negativamente o valor nutricional da planta forrageira. O período de diferimento de 75 dias a partir de março favoreceu a concentração de macronutrientes e o teor de PB no capim marandu tanto em MC quanto nos SSP.

Palavras-chave: grama forrageira**;** macronutrientes; proteína; sistema diversificado; valor nutritivo.



Introduction

The availability of food for grazing animals is influenced by climate variations, which constitute fundamental factors contributing to the seasonality of forage production. In this context, the water deficit characteristic of the dry period leads to important changes in plant interactions with the environment, with considerable alterations in the nutritional value of forages and their structural composition (e.g., leaf, stem, and root)[(1)].

Stockpiling is a management strategy that aims to accumulate forage to be supplied to animals during periods of food scarcity, minimizing the effects of seasonality on forage production marked by water deficit[(2)]. Pasture stockpiled for long periods generally has a higher accumulation of dead forage in its composition, consisting of a fraction that is more fibrous and has lower nutritional value due to senescence[(3)].

The structural characteristics of stockpiled pasture can make it less predisposing to intake during grazing, compromising animal performance(4). For this reason, the sealing time must be planned. Soil moisture has a major impact on the diffusion of nutrients, which may reduce their access to plants(5). Pasture analysis is an essential tool for identifying food insufficiency, as well as unfavorable mineral balances, which can induce deficiency in plants and, consequently, in animals(6).

Diversified systems such as the silvopastoral system (SPS), including the tree component, forage plants, and animals in the same area, have been proposed as an alternative to pasture monoculture (MC). This system has conservation characteristics that benefit the maintenance of the forage nutritional value(7-8).

Some limitations can affect the grass if the system is prepared inappropriately despite its favorable characteristics. Excessive shading can limit the forage production potential in SPS(9), causing not only leaf elongation as a form of plant adaptation(10) but also stem elongation as a plant strategy in the search for light(11).

Management actions that result in higher percentages of green leaf blades and vegetative tillers in the pasture contribute to improving the nutritional value of the stockpiled forage, as these components have high protein concentrations(12). Therefore, grasses of the genus *Urochloa* are recommended for stockpiling because they have less reduction in nutritional value over time and can still adapt physiologically to shaded environments, as is the case of Marandu grass(13).

This study hypothesized that the spacing adopted in the arrangement of silvopastoral systems could favor higher nutritional input and mineral composition in Marandu grass subjected to different stockpiling periods. The objective was to evaluate the effect of different spatial arrangements between the rows of *Eucalyptus urophylla* trees in SPS associated with different stockpiling periods relative to the nutritional attributes and mineral composition of Marandu grass.

Material and methods

The study was conducted on the experimental farm of the Federal Institute of Education, Science, and Technology of Tocantins, at the campus of Colinas do Tocantins – TO, Brazil, located in the northern region of the state on the BR-153 highway (8°5′22″ S latitude, 48°28′33″ W longitude, 223 m of altitude). According to the Köppen classification, the regional climate is AW (hot and humid)(14), showing a dry period from May to September, with a mean annual temperature of 28 °C and mean annual rainfall of 1,800 mm. Figure 1 shows the mean data on maximum and minimum temperatures and monthly accumulated precipitation during the experimental period.

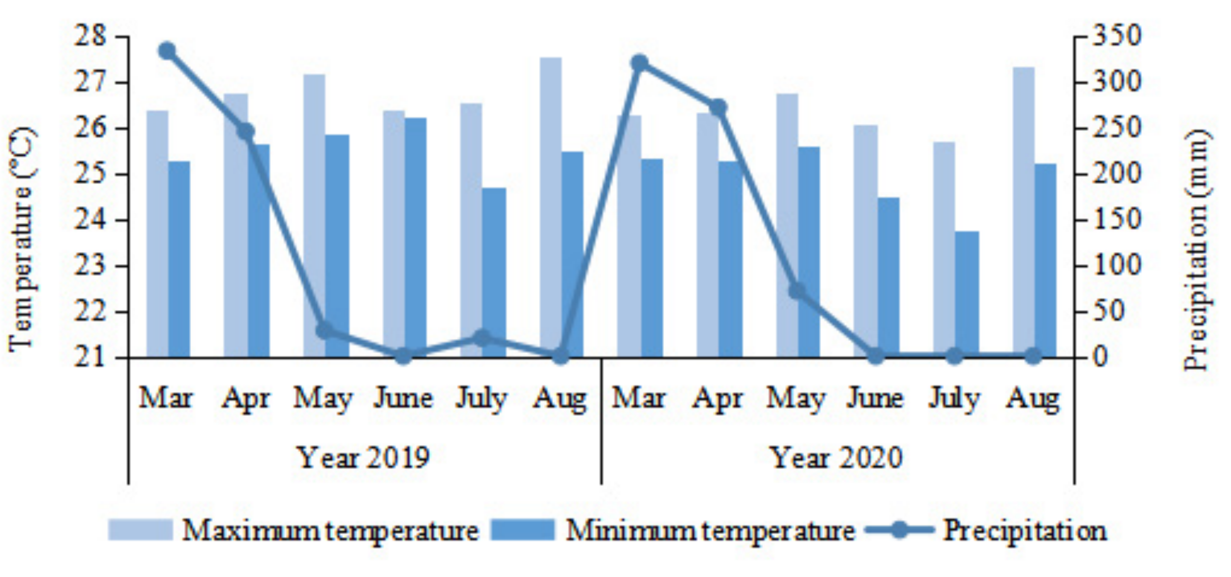


Figure 1 **Monthly means of maximum and minimum temperatures and precipitation from March to August 2019 and 2020.**

The total area of the experiment covers 2.4 ha and was implemented in 2016, with the planting of *Eucalyptus urophylla* (using 15-cm seedlings) in rows positioned in an east-west direction, with 2 m between trees within the rows and 18 (18 × 2 m) and 12 m (12 × 2m) between rows within the tree rows, which were approximately 15- to 18-m high. The grass *Urochloa brizantha* (Hochst. Ex. A. Rich.) Stapf cv. Marandu was implemented in the same year and space.

The experiment was conducted in a randomized block design, in which each system was allocated individually. Each treatment was formed in the center of each plot (670 m^2) in a 3 × 4 factorial arrangement, consisting of three systems (monoculture and silvopastoral with 12 and 18 m between tree rows) and four stockpiling periods (60, 90, 120, and 150 days), making up 12 treatments with three replications, totaling 36 plots.

The experiment was carried out from March to August 2019 and 2020. The soil was collected at a depth of 0−20 cm for physicochemical characterization (Table 1), classified as an Entisol (*Neossolo Quartzarênico Órtico típico*)[15].

Table 1 **Chemical characteristics of soil samples from the experimental area collected at a depth of 0–20 cm.**

System	pH	OM	P (Mehl.)	Ca	Mg	K	H + Al	SB	CEC	BS
	CaCl2	g dm-3	Mg dm-3			---------------cmolc dm-3---------------				%
SPS 12 m	4.9	16	0.9	1.1	0.8	0.01	1.7	1.9	3.6	53
SPS 18 m	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

SPS – silvopastoral system; OM – organic matter; SB – sum of bases; CEC – cation-exchange capacity; BS – base saturation.

A cut to standardize the pasture areas was carried out 20 cm from the ground using a backpack brushcutter on March 16, 2019 and 2020, respectively. Maintenance fertilization was carried out in a single dose for each year of evaluation (2019 and 2020), considering the nutritional requirements of the grass and the technological level of each system, as described by Santos et al.(16), that is, 50 kg ha^{-1} of nitrogen (N) (urea), 70 kg ha^{-1} of phosphorus (P) (single superphosphate – P2O5), and 50 kg ha^{-1} of potassium (P) (potassium chloride – K2O), to replenish nutrients for full grass development.

Three samples were taken per plot, using a 0.25-m^2 metal frame (launched twice at uniform points) to collect the entire forage mass contained inside, observing a stubble height of 20 cm. The forage was packed in plastic bags, weighed, and taken to the laboratory to continue the analysis procedures.

An aliquot of the collected forage was separated, packaged in identified paper bags, weighed on an electronic scale, and subjected to pre-drying in a forced-air circulation oven at 55 °C for 72 h or until constant weight. The samples were weighed again after the drying period to determine the dry mass. Subsequently, the sample was ground in a Wiley mill using a 1-mm-opening sieve and separated into two aliquots. Then, the forage aliquots were analyzed for total nitrogen content (crude protein – CP), using the Kjeldahl method, and neutral detergent fiber (NDF) and acid detergent fiber (ADF) following the methodology proposed by Van Soest and described by Detmann et al.(17).

The second aliquot of the samples was placed in porcelain crucibles and incinerated in an electric muffle furnace at a temperature ranging from 500 and 550 °C. The ash resulting from burning in the furnace was analyzed by the dry method for phosphorus (P) contents by molybdenum blue colorimetry, potassium (K^+) by atomic emission spectrometry, and calcium (Ca^{2+}) and magnesium (Mg^{2+}) by titration with EDTA, following the methodology described by Nogueira et al.(18).

The data were subjected to normality and homoscedasticity tests. The year effect was included in the statistical model to perform the analyses. A test of means was performed for qualitative variables and regression analysis for the stockpiling periods. All statistical analyses were performed at a significance level of up to 5% probability using the SISVAR program for statistical analysis and experimental design (19).

Results and Discussion

No interaction effect was observed between the evaluated systems and the stockpiling period for the analyzed variables ($p>0.05$). The crude protein content reduced linearly with increasing stockpiling period ($p<0.05$). Changes in the nutritional value of the forage over the days under stockpiling were already expected (Figure 2) due to the structural and physiological changes that affect the stockpiled grass.

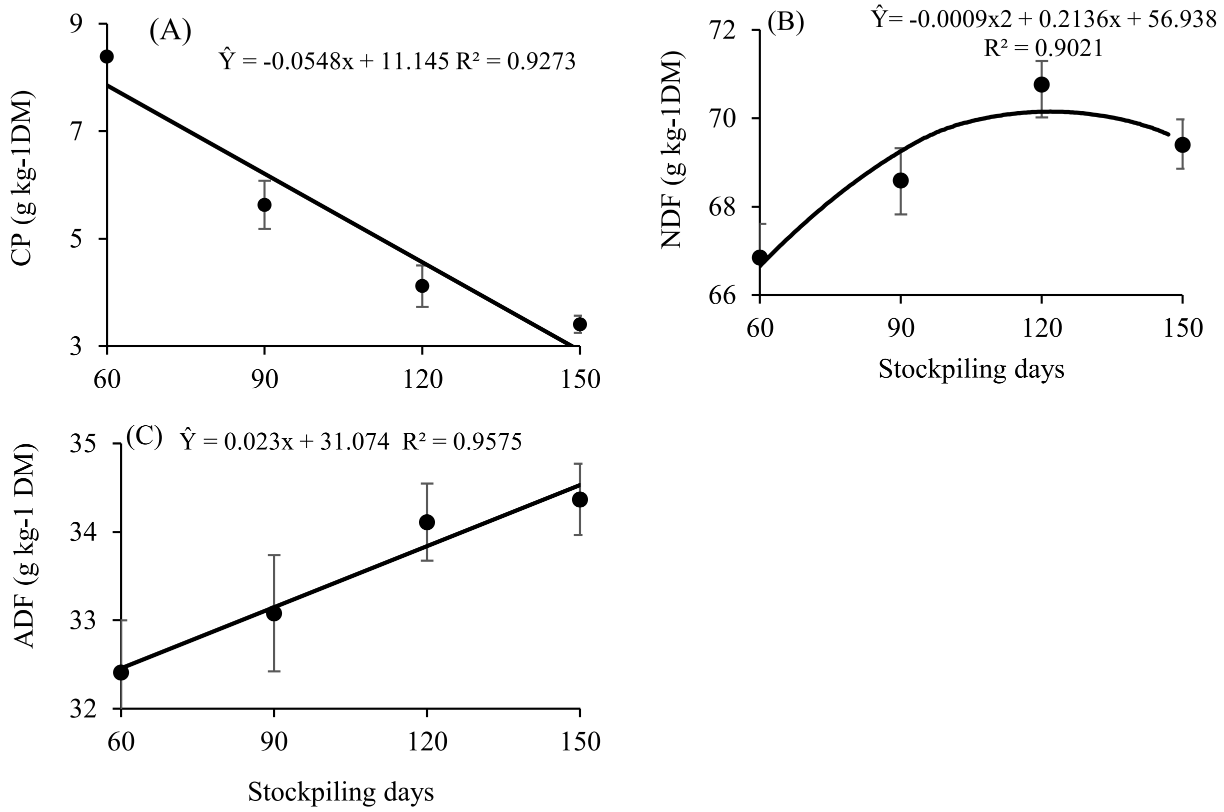


Figure 2 **Crude protein (CP; A), neutral detergent fiber (NDF; B), and acid detergent fiber (ADF; C) contents in Marandu grass throughout days of stockpiling in silvopastoral and monoculture systems.**

Grasses that remain exposed to water deficit for a long period exhibit a larger mass of dead tissue. This transformation occurs at an accelerated rate as a consequence of water deficit (Figure 1) and compromises the nutritional value of the forage, reducing it considerably(20).

The high CP values at the beginning of the sealing period were a result of the substantial proportion of green components in the forage, such as leaves and tillers. These components develop in response to favorable conditions, such as the water availability present in the soil in the initial phase of stockpiling, as CP concentrations in the forage vary with precipitation and temperature(21). Young tissues such as tillers have a high CP concentration. This is because they have lower proportions of structural carbohydrates(22), which in turn increase as the plant develops and require a higher supply of tissues that make it possible to support the plant in an upright position.

Exposure to water deficit and soil warming impairs gas exchange, biomass production, and forage quality, increasing fiber contents and reducing protein contents, as well as forage digestibility(20). Crude protein contents up to 75 days of stockpiling met the minimum nutritional requirement of ruminal microorganisms, which is 7% in the forage dry mass(21). After this period, forage intake would result in poor animal performance on grazing.

Pezzopane et al.(7) observed positive effects of shading on grass quality in integrated systems, with proximity to the tree canopy resulting in higher CP contents. Sousa et al.(23) found a 37% higher CP content in forage grown in an intercropping environment when compared to the monoculture system. However, the results observed in the present study differ from those reported by these authors. This can be attributed to the age of the eucalyptus (between three and four years), with a poorly developed crown (between 15 and 18 m in height), considering the adopted spacing. Thus, the shading imposed by the trees was not able to change the nutritional value of the grass.

The environment under the tree canopy reduces transpiration losses, which helps the grass remain green for a longer period, with a positive impact on the nutritional quality of the forage. The results indicate that climate conditions (drought) characteristic of the period under study certainly increased the proportion of senescent material, eliminating the differences between monoculture and shaded systems and reducing the CP content of the pasture in all systems (Figure 2), as observed by Pezzopane et al.[(7)].

The NDF concentration exhibited a quadratic response, whereas ADF increased with increasing stockpiling ($p<0.05$) (Figures 2B and C). These two components act antagonistically relative to CP concentrations. According to the natural growth cycle, forage plants lack physiological adaptations that lead to the synthesis of structural tissues, such as stem mass with high NDF and ADF content[(24)], as leaves have the highest nutritional value among green morphological components[(25)]. As with structural tissues, tissue senescence reduces the proportion of potentially digestible components and reduces the nutritional quality of forage[(2-3)].

Shading was expected to increase the CP content and reduce NDF in the silvopastoral system, as observed by Paciullo et al.[(24)]. However, the systems did not affect these variables, as observed by Silva[(22)], whose results showed that NDF and CP contents did not differ between the monoculture and the silvopastoral system evaluated in the dry period, although both systems showed higher concentrations during the rainy season.

Forage digestibility is directly related to its composition since the CP content decreases as fiber increases[(1)]. The results indicate that an increase in stockpiling days favors a morphological composition, which increases tissue senescence, leading to a reduction in the nutritional value and promoting selection by grazing animals due to the preference for consuming live leaves[(4)]. A reduction in the stockpiling period is the most appropriate management strategy if the objective is to maintain the pasture with the best possible nutritional value during sealing.

The chemical composition and digestibility of forages vary depending on the species, maturity stage, and climate factors, such as water scarcity, among other factors. The role of temperature is pivotal in determining forage quality. Plants cultivated under elevated temperatures, particularly during the summer, experience accelerated metabolic activities. This acceleration leads to a reduction in the array of metabolites within cellular content, with photosynthetic products swiftly converting into structural components, ultimately contributing to heightened cell wall lignification[(21)].

The 150-day stockpiled grazing occurred during the peak temperatures (exceeding 27 °C) recorded over the two evaluation years. Forage plants grown in hotter, drier regions generally have lower nutritional value, indicated by higher fiber, higher lignin, and lower protein content, making them less digestible than those grown in cooler, wetter regions[1].

Moderate shading in the silvopastoral system does not interfere with the pasture carrying capacity, nutritional value, dry matter intake, or animal performance compared to the monoculture system[26]. Therefore, variations in CP, NDF, and ADF contents found in this study are more closely related to the stockpiling period and the dry season[27].

Phosphorus and K contents decreased with increasing stockpiling ($p<0.05$) (Figure 3). The increase in stockpiling leads the plant to interrupt nutrient uptake, indicating that the water deficit, as well as the unavailability of nutrients in the soil solution, may have accelerated senescence.

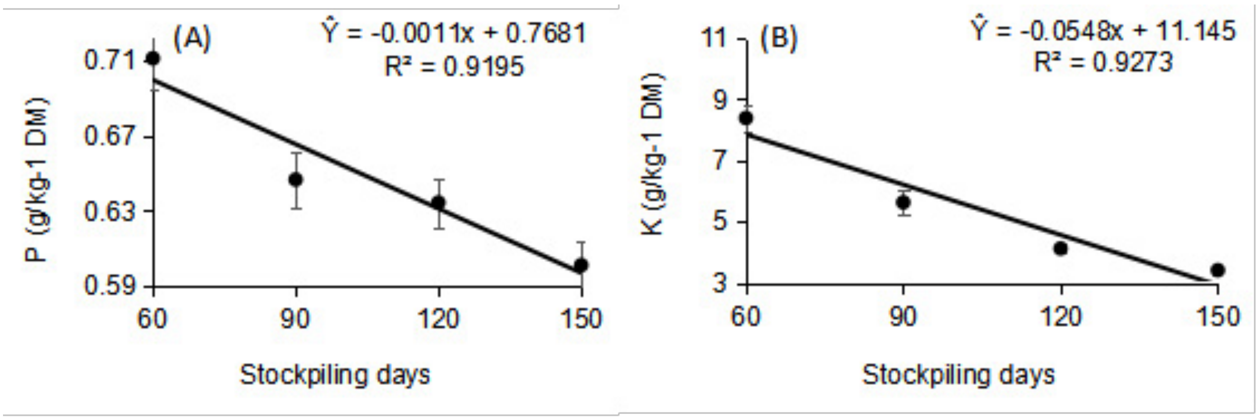


Figure 3 **Phosphorus (P; A) and potassium (K; B) contents of Marandu grass under stockpiling days in silvopastoral and monoculture systems.**

Shading imposed by the tree component may increase P content in tropical forages[28], but this behavior was not observed (Figure 3A). Thus, water stress reduces P uptake, causing the limitation of this nutrient in plants[5]. In fact, P uptake occurs through the movement of the nutrient in the soil, which is governed by the diffusion phenomenon, characterized by the movement of ions down a concentration gradient, and this process depends on water[29].

Higher nutrient uptake is observed at the beginning of stockpiling due to the high metabolic rates during the plant development period. However, the advancement in the plant development stage leads to nutrient dilution. The concentration of potentially digestible components, including soluble carbohydrates, proteins, and minerals, tends to decrease due to the maturation of plant tissues[3].

The decrease caused by the increasing stockpiling for K contents (Figure 3B) is explained by a decline in forage productivity, stemming from the low synthesis of new tissues and growth of existing ones, indicating that environmental factors acted as limiting factors for uptake by the grass. Shading displayed a significant effect on K content when evaluating *Urochloa brizantha* grass, as observed by Castro et al.[28]. but no similar result was found.

Stomatal conductance, transpiration rate, and photosynthesis are often decreased under drought conditions, leading to reduced nutrient uptake and biomass accumulation[20]. The mineral composition of leaves is important for the nutritional quality and digestibility of forage species used in livestock farming, as animals obtain energy and nutrients mostly from leaves, which can affect animal performance[30].

Many pastures have Ca, Mg, Na, and K concentrations that are low or imbalanced for ruminants[31]. For instance, the requirement for a steer weighing 350 kg, aiming at a daily weight gain of 0.5 kg, in a forage plant would be N = 11.2, P = 0.5, K = 6.0, Ca = 1.2, and Mg = 1.0 g kg^{-1} of dry matter[32]. In this study, P and K values were supplied and, in the case of K, the optimal condition occurred until 80 days of stockpiling.

The poor performance of pastures in providing adequate nutrients in the dry season[33] leads animals to lose weight or even be unable to maintain the gained weight. For this reason, supplementing grazing animals, especially in periods with low forage production, is a common practice. The relatively low nutrient concentrations in summer forage can be attributed to hot, dry conditions, which reduce nutrient demand and uptake by plants.

Magnesium and Ca concentrations did not differ during the stockpiling period, but Mg showed a difference ($p<0.05$) relative to the evaluated systems (Table 2). Magnesium did not differ between MC and SPS12, as both expressed higher values relative to that observed for SPS18. The Mg concentration in forage grass can vary from 1.2 to 2.2 g kg^{-1} DM[34] based on adequate nutrition. The values observed here are below those reported by these authors.

Magnesium makes up the chlorophyll molecule, being essential for the photochemical and metabolic reactions of plants and showing great importance for ruminants because its deficiency or low availability causes a nutritional disorder called tetany[28].

Table 2 **Calcium (Ca) and magnesium (Mg) contents of Marandu grass in monoculture and silvopastoral systems with 12 (SPS12) and 18 m (SPS18) spacing between tree rows.**

System	Ca (g kg–1 DM)	P-value	Mg (g kg–1 DM)	P-value
Monoculture	0.48 A	<0.0769	0.59 A	<0.0004
SPS12 m	0.48 A		0.57 A	
SPS18 m	0.42 A		0.40 B	
Mean	0.46		0.59	
CV (%)	15.84		20.73	

In response to water scarcity, the plant manifests a mechanism involving senescence, a process wherein nutrient requirements decrease due to a slowdown in metabolism during this stage. The increase in nutrient availability and uptake is directly related to increased growth and productivity[34].

Roots are unable to obtain the required amounts of nutrients from the soil under water deficit, resulting in metabolic disturbances and negative effects on plant growth[35]. The detrimental effect of drought on biomass production is associated with a reduction in the uptake of macronutrients such as N, P, K, Ca, and Mg[5].

Conclusion

Our results suggest that Marandu grass can be used intercropped in a silvopastoral system with an arrangement of 12 and 18 m between rows of trees planted in an east-west direction without this arrangement negatively influencing the nutritional value of the forage plant. The 75-day stockpiling period from March favored the macronutrient concentrations and crude protein content in Marandu grass in both monoculture and silvopastoral systems.

Declaration of conflict of interest

The authors declare no conflicts of interest.

Author contributions

Conceptualization: R. P. Lages e A. C. Santos. *Data curation*: R. P. Lages. Formal analysis: R. P. Lages. *Funding acquisition:* A. C. Santos. Investigation: R. P. Lages, R. P. Araújo e W. S. Lino. *Project administration*: R. P. Lages. *Methodology*: R. P. Lages, A. C. Santos e R. P. Araújo. *Resources*: A. C. Santos. *Supervision*: A. C. Santos e R. P. Araújo. Visualization: R. P. Lages. *Writing (original draft)*: R. P. Lages. *Writing (review & editing)*: R. P. Lages, A. C. Santos, R. P. Araújo, M. M. Souza e J. S. Oliveira.

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