

PHOSPHATE FERTILIZATION IMPROVE PRODUCTIVITY AND CHEMICAL-BROMATOLOGICAL COMPOSITION OF LEAF BLADE OF UNBURNED PASTURE

A ADUBAÇÃO FOSFATADA MELHORA A PRODUTIVIDADE E A COMPOSIÇÃO QUÍMICO-BROMATOLÓGICA DA LÂMINA FOLIAR DE PASTAGEM NÃO QUEIMADA

LA FERTILIZACIÓN FOSFATADA MEJORA LA PRODUCTIVIDAD Y LA COMPOSICIÓN QUÍMICO-BROMATOLÓGICA DE LA LÁMINA FOLIAR DE PASTURAS NO QUEMADAS



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ABSTRACT

We evaluate the effects of phosphate fertilization on the leaf blade productivity of unburned *Brachiaria brizantha*, cv. Marandu, as well its chemical-bromatological composition compared to the pasture burning in the southwestern Amazon. Brazilian Amazon has one of the highest proportion of planted pastures in Brazil and the *Brachiaria brizantha* is the most used species. The burning is an important factor that lead to the gradual degradation of pastures. These circumstances generate pastures with low capability of providing feed for cattle farming. The improvement caused by burnings occurs only in short periods after burning. Some alternative sources with a low content of soluble P, in turn, increases biomass productivity and the nutritional value of cultivated species. A field experiment was carried out in a completely randomized blocks design. The treatments consisted of unburned pasture treated with 0, 25, 100 and 200 kg ha⁻¹ of P compared to the pasture burning. After applying the treatments, the pasture was desiccated in order to homogenize the plant emergence and growth after the period without rain from July to September. The dose of 100 kg ha⁻¹ of P for unburned pasture promoted better productivity and mineral nutrient concentrations, and leaf quality for animal consumption was improved. Values of acid detergent fiber, neutral detergent fiber, lignin and crude protein indicate an adequate bromatological composition of leaf for animal consumption at 56 days of growth. The practical and theoretical implications of this research are discussed, providing insights into how the results can be applied or influence practices in the field of pasture management without fire using. These implications could encompass on how to apply and how much of an alternative phosphate must be applied to the soil to supply phosphorus for *B. brizantha* instead of using fire in the pasture management. This study contributes to the literature by highlighting the superiority of phosphorus application from alternative sources allied to N and K fertilization compared to the pasture burning practice in the Southwestern Amazon. This innovative approach can be used as a base for new researches and applied in the level of cattle farmers.

Keywords: Dry Mass. Fire. Livestock. Supression. Sustainability.

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RESUMO

Avaliamos os efeitos da adubação fosfatada sobre a produtividade da lâmina foliar de *Brachiaria brizantha* cv. Marandu em pastagem não queimada, bem como sua composição químico-bromatológica, em comparação com a prática da queima de pastagens no sudoeste da Amazônia. A Amazônia brasileira possui uma das maiores proporções de pastagens plantadas do Brasil, sendo a *Brachiaria brizantha* a espécie mais utilizada. A queima é um fator importante que leva à degradação gradual das pastagens, gerando áreas com baixa capacidade de fornecimento de alimento para a pecuária, e a melhoria proporcionada por essa prática ocorre apenas por curtos períodos após sua realização. Algumas fontes alternativas, com baixo teor de fósforo solúvel, por sua vez, aumentam a produtividade de biomassa e o valor nutricional das espécies cultivadas. O experimento de campo foi conduzido em delineamento de blocos completamente casualizados, com tratamentos consistindo em pastagem não queimada submetida às doses de 0, 25, 100 e 200 kg ha⁻¹ de P, comparadas à pastagem queimada. Após a aplicação dos tratamentos, a pastagem foi dessecada com o objetivo de homogeneizar a emergência e o crescimento das plantas após o período sem chuvas, de julho a setembro. A dose de 100 kg ha⁻¹ de P na pastagem não queimada promoveu maior produtividade, melhores concentrações de nutrientes minerais e melhoria da qualidade da folha para o consumo animal, sendo que os valores de fibra em detergente ácido, fibra em detergente neutro, lignina e proteína bruta indicaram composição bromatológica adequada da lâmina foliar aos 56 dias de crescimento. As implicações práticas e teóricas desta pesquisa são discutidas, fornecendo subsídios sobre como os resultados podem ser aplicados ou influenciar práticas no manejo de pastagens sem o uso do fogo, incluindo orientações sobre como e quanto de uma fonte alternativa de fosfato deve ser aplicada ao solo para suprir fósforo para *B. brizantha* em substituição à queima no manejo das pastagens. Este estudo contribui para a literatura ao evidenciar a superioridade da aplicação de fósforo proveniente de fontes alternativas associada à adubação com N e K em relação à prática da queima de pastagens no sudoeste da Amazônia, configurando uma abordagem inovadora que pode servir de base para novas pesquisas e ser aplicada em nível de produtores pecuários.

Palavras-chave: Massa Seca. Fogo. Pecuária. Supressão. Sustentabilidade.

RESUMEN

Se evaluaron los efectos de la fertilización fosfatada sobre la productividad de la lámina foliar de *Brachiaria brizantha* cv. Marandu en pasturas no quemadas, así como su composición químico-bromatológica, en comparación con la práctica de quema de pasturas en el suroeste de la Amazonía. La Amazonía brasileña presenta una de las mayores proporciones de pasturas cultivadas del país, siendo *Brachiaria brizantha* la especie más utilizada. La quema es un factor importante que conduce a la degradación gradual de las pasturas, generando áreas con baja capacidad para suministrar alimento a la ganadería, y la mejora ocasionada por esta práctica ocurre únicamente en cortos períodos posteriores a su aplicación. Algunas fuentes alternativas, con bajo contenido de fósforo soluble, incrementan la productividad de biomasa y el valor nutricional de las especies cultivadas. El experimento de campo se realizó bajo un diseño de bloques completamente al azar, con tratamientos consistentes en pasturas no quemadas sometidas a dosis de 0, 25, 100 y 200 kg ha⁻¹ de P, comparadas con pasturas quemadas. Tras la aplicación de los tratamientos, la pastura fue desecada con el fin de homogeneizar la emergencia y el crecimiento de las plantas después del período sin lluvias, entre julio y septiembre. La dosis de 100 kg ha⁻¹ de P en pasturas no quemadas promovió mayor productividad, mejores concentraciones de nutrientes minerales y una mejora en la calidad foliar para el consumo animal, y los valores de fibra detergente ácida, fibra detergente neutra, lignina y proteína bruta indicaron una composición bromatológica adecuada de la lámina foliar a los 56 días de crecimiento. Se discuten las implicaciones prácticas y teóricas



de esta investigación, aportando elementos sobre cómo los resultados pueden aplicarse o influir en las prácticas de manejo de pasturas sin el uso del fuego, incluyendo orientaciones sobre cómo y cuánto de una fuente alternativa de fosfato debe aplicarse al suelo para suministrar fósforo a *B. brizantha* en sustitución de la quema en el manejo de pasturas. Este estudio contribuye a la literatura al destacar la superioridad de la aplicación de fósforo a partir de fuentes alternativas asociada a la fertilización con N y K en comparación con la práctica de quema de pasturas en el suroeste de la Amazonía, constituyendo un enfoque innovador que puede servir de base para nuevas investigaciones y ser aplicado a nivel de productores ganaderos.

Palabras clave: Materia Seca. Fuego. Ganadería. Supresión. Sostenibilidad.

1 INTRODUCTION

The area for cattle breeding in Brazilian Amazon has one of the highest proportion of planted pastures in Brazil (Baggio *et al.*, 2021). The *Brachiaria brizantha* is the most used species in pasture-based systems (Silva *et al.*, 2016b). Nevertheless, cattle overgrazing and the lack of soil nutrient reposition, besides the high release and loss of nitrogen (N), phosphorus (P) and potassium (K) to the soil and forms of carbon (C) and N to the atmosphere (Rumpel *et al.*, 2015; Dias-Filho, 2014b; Luizão *et al.*, 2013) caused by burning are factors that lead to the gradual degradation of pastures, like in the southwestern Amazon.

These circumstances generate pastures with low capability of providing feed (leaves) for cattle farming (Pequeno *et al.*, 2015). Cardoso *et al.* (2003) confirmed that when verified just a slight superiority on the nutritional value of dry mass of *Andropogon bicornis* grass burned only in the first months after the fire application. This finding is attributed to the ashes produced by the fire, which provide available forms of nutrients for freshly sprouting plants (López-Mársico *et al.*, 2019). However, there is evidence that even the improvement caused by burnings on soil attributes and nutrient availabilities occurs only in short periods after burning (Dick *et al.*, 2008). Girona-García *et al.* (2018) studied subalpine vegetation that includes grasses. In twelve months after burning, they detected a decrease on topsoil nutrient availability. Despite that, the line of thinking that still persists around the world is that burning stimulates the regrowth of grasses with high nutritional value for grazing animals (Van Der Werf *et al.*, 2008).

On the other hand, cattle breeders in the southwestern Amazon region resort to this practice because they do not have governmental incentives to change the way they have done pasture biomass production for cattle feed. They are limited by the common lack of credit to the adoption of technical knowledge (Aryal *et al.*, 2020) to recover soil fertility and biomass productivity. That situation leads to the continuous use of fire as a strategy for managing *B. brizantha* that shows to be unproductive and with a low long-term nutritional value.

In turn, the low soil P availability limits pasture production on the nutrient-poor soils of the southwestern Amazon (Campos *et al.*, 2012). In that region, the phosphate fertilization and burning suppression, as observed by other authors, can increase P availability and the biomass productivity of different planted pastures (Aryal *et al.*, 2020; Souza *et al.*, 2020; Farias *et al.*, 2016; Marahata *et al.*, 2014).

There is a lack of information about biomass productivity and chemical-bromatological quality of leaf blade on not burned pasture under the effects of phosphate fertilization compared to the periodical burning on the Amazon livestock agroecosystems. Considering

these information, we evaluate the effects of phosphate fertilization with burning suppression on the leaf blade productivity of *Brachiaria brizantha* (Hochst ex A. Rich.) Stapf. cv. Marandu as well its chemical-bromatological composition compared to pasture burning in the southwestern Amazon.

2 THEORETICAL FRAMEWORK

Relative similar studies to this one on P for pasture fertilization have been carried out with different sources of the nutrient, whether or not in a soluble form, whether or not at the same time, to N sources in order to evaluate the production, chemical composition and nutritional value of *Brachiaria* spp (Ieri *et al.*, 2010; Magalhães *et al.*, 2007; Machado; Valle, 2011). Heringer; Jackes (2002c) found higher dry mass yields and CP contents on areas where the soil was corrected and fertilized compared to the burning. These authors observed that the P, K, Ca and Mg contents were higher in the dry mass on the area that received fertilization and, additionally, the burning reduced the amount of nutrients in the pasture. Porto *et al.* (2012) applied increasing doses of soluble P for *Brachiaria brizantha* cv. Marandu and observed 24% higher dry matter production on leaves at the dose of 147 kg ha⁻¹ of P₂O₅ compared to the absence of fertilization. According to Machado *et al.* (2011), the increase of the P dose increases the nutrient content on pasture leaf tissue.

In this sense, some alternative P sources with a low content of soluble P, like partially acidulated phosphate rocks, bring other nutrients in their composition, such as calcium (Ca), magnesium (Mg) and sulfur (S). That fact is important because S and Mg has its own availability improved together with P availability that, in turn, increases biomass productivity (Hopkins; Hansen, 2019) and, possibly, the nutritional value of cultivated species. According to Silva; Lobo (2024), the application of 100 kg ha⁻¹ of phosphorus from alternative phosphate rock and nitrogen and potassium fertilization increase topsoil availability and absorption and accumulation of P, Mg and S by *B. brizantha*. Their results indicate, additionally, that even the absence of P application with nitrogen and potassium fertilization shows to be superior to the burning, becoming this practice unnecessary to the pasture management.

Pastures have been seen as a potential reducer of greenhouse gases (GHG) emissions by the inputs on soil surface biomass, providing animal products for human consumption and increasing the sustainability of livestock farming (Mottet *et al.*, 2017; Vetter *et al.*, 2017; IPCC, 2014; Gerber *et al.*, 2013a, b). Inputs on the biomass productivity mean pasture restoration and available feed for cattle farming (Lal, 2011; Conant, 2010). In this sense, well-fertilized pastures provide important environmental services to the ecosystems

(Sollenberger et al., 2019) by suppressing the burnings, being considered a strategy for mitigating climate change (Lal, 2011; Conant, 2010).

3 METHODOLOGY

B. brizantha not burned and fertilized with four doses of P was compared to simple pasture burning in the field conditions. The experiment was performed from September to November 2015 at the Vanazzi Cattle Farm, BR 319, km 12, on a transition between the Amazon forest and natural fields in Humaitá (7° 35' S and 63° 6' W, 90 m a.s.l.), southwestern Amazon. The climate of the region is Af according to Köppen climate classification, and present a rainy season from September to July, mean air temperature of 26.5 °C. The total annual rainfall is 2500 mm and the relative humidity ranges from 85% to 90%.

The experimental area measured 25.0 m x 45.0 m of an acidic Oxisol (Alic Cambisol) (Santos et al., 2018) homogeneously covered by *Brachiaria brizantha* (Hochst ex A. Rich.) Stapf. cv. Marandu, at stage II of degradation according to Dias-Filho (2011b). The pasture was not burned or grazed from September 2014 to September 2015. A manual extraction of weeds in September 2014 made that practice unnecessary in 2015, since the rapid pasture growth covered the soil and suppressed 100% of these plants.

For the establishment of blocks and plots on the experimental area, a homogeneous cutting process with garden shears levelled the pasture at a 0.20 m height at 07/23/2015, in order to simulate the traditional Amazon grazing of a hundred percent of the pasture leaf area. At 09/12/2015, the blocks were established at a subarea on the experimental area. The plots measured 4.50 m in length by 3.50 m (15.75 m²) and 0.80 m in the borders (Cayley; Bird, 1996). Plot delimitation was carried out with nylon threads fixed to the end of iron bars vertically fixed to the ground. On 09/13/2015, a representative 0.60 kg soil sample (20 simple samples) was collected from the area at 0.0-0.05 m depth (topsoil layer) with the aid of a dutch auger (*TF10-Sonda Terra, Piracicaba, Brazil*). A 0.40 kg subsample was air-dried and broken and passed through a 2.0 mm sieve for the chemical and physical analysis, prior the experiment.

The topsoil presented (Silva, 2009): pH (water) = 5.00, Al³⁺ = 1.02 cmol_c dm⁻³, H+Al = 5.00 cmol_c dm⁻³, Ca²⁺ = 2.01 cmol_c dm⁻³, Mg²⁺ = 1.50 cmol_c dm⁻³, K⁺ = 0.09 cmol_c dm⁻³, CEC = 8.33 cmol_c dm⁻³, SB = 4.50 cmol_c dm⁻³, P (Mehlich-1) = 3.0 mg dm⁻³, V = 42%, m = 8.75%, SOC = 11.36 g kg⁻¹, Cu²⁺ = 4.25 mg dm⁻³, Fe = 297.59 mg dm⁻³, Mn²⁺ = 8.02 mg dm⁻³, Zn = 2.29 mg dm⁻³. A 0.20 kg topsoil subsample was analysed for: B (hot water) = 0.08 mg dm⁻³, and SO₄²⁻ = 9.0 mg dm⁻³ (Raij et al. 2001). The topsoil presented: sand = 349.7, silt = 452.15 and clay = 181.87 g kg⁻¹ (EMBRAPA, 1997).

The following treatments were applied: Pnb = *B. brizantha* not burned; Pnb+25 = Pnb + 25.0 kg ha⁻¹ of P; Pnb+100 = Pnb + 100.0 kg ha⁻¹ of P; Pnb+200 = Pnb + 200.0 kg ha⁻¹ of P for comparison to the pasture burned, represented by Pb = burning of *B. brizantha*, with 4 replicates. A partially acidulated phosphate rock (PPR) was used as the P source and its chemical and granulometric characteristics (Brasil, 2014) are provided in the Table 1.

The P doses were applied at 09/14/2015, after a rainfall higher than 2.0 mm (Figure 1) by manual and homogeneous distribution of 0.0, 0.22, 0.88 and 1.76 kg plot⁻¹ of PPR, dry mass, to the soil surface of the plots for supplying, respectively, the Pnb, Pnb+25, Pnb+100 and Pnb+200. The Pb was applied after removal of the nylon threads that delimited the plots, and after the firebreaks establishment around the area reserved for each plot of this treatment. Firstly, the fire was set in the center of each plot area and controlled with water spray in the boundaries. Then, the plots were delimited again with the nylon thread relocation on to the end of the vertically fixed iron bars.

Table 1

Chemical characteristics and granulometry of the partially acidulated phosphate rock¹.

Phosphorus source	Total phosphorus contente				Granulometric fraction retention (mm) ⁶						
	TP ²	TP ₂ O ₅ ³	P ₂ O ₅ (CNA+H ₂ O) ⁴	P ₂ O ₅ (H ₂ O) ⁵	0.075	0.10	0.25	0.50	1.0	2.0	4.0
PPR ^A	----- g kg ⁻¹ -----				----- g kg ⁻¹ -----						
	118.00	270.00	76.30	28.30	64.0	150.70	236.80	300.30	40.60	0.00	0.00
	Other macronutrients				Micronutrient						
	Ca	Mg	S		B	Cu	Fe	Mn	Zn	Mo	
	----- g kg ⁻¹ -----				----- mg kg ⁻¹ -----						
	141.60	8.60	41.35		0.04	0.09	62.90	5.90	0.20	<0.01	

¹partially acidulated phosphate rock Alvorada (SOCAL, Registro, SP), ²TP: total phosphorus content, ³TP₂O₅: total P₂O₅ content, ⁴P₂O₅ (CNA+H₂O): total P₂O₅ content in neutral ammonium citrate + water, ⁵P₂O₅ H₂O: P₂O₅ water soluble, ⁶207.4 g kg⁻¹ of PPR passed in the 0,075 mm sieve.

The homogenization of plant emergence and physiological development of *B. brizantha* was performed at 09/18/2015 in all experimental plots. This procedure consisted of the desiccation of newly emerged tillers by pulverizing 200 L ha⁻¹ of gramoxone 200 syrup.

Brazil) at 67 °C for 72 hours. The LDM dry mass productivity was obtained by weighing on a precision scale (*Tecnal, SHI-BL-3200H, Piracicaba, Brazil*) whose values, g jig^{-1} , were converted to t ha^{-1} in an Excel worksheet.

Twenty five percent of the leaf blade dry mass were separated for the chemical analysis of N, P, K, Ca, Mg, S (g kg^{-1}), B, Cu, Fe, Mn and Zn (mg kg^{-1}) according to Silva (2009). Another 25% of the LDM were kept properly packaged on a triple plastic bag and refrigerated until entering the Laboratory of Animal Nutrition of Universidade Federal do Paraná, Curitiba, Brazil, where the samples were ground for the analysis of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin (LIGN), according the methodologies of the AOAC (1990).

Experimental data of leaf blade dry mass productivity and chemical-bromatological composition of the leaf blade of *B. brizantha* were subjected to Cochran's homocedasticity test ($p \geq 0.05$). The significance of means was identified with the F-test ($p \leq 0.05$) in the MStatC Software (Michigan State University, USA), in accordance with a randomized block experimental design. The means comparison was carried out with Tukey's test ($p \leq 0.05$) in the same software. Pearson's linear correlation among the data of leaf blade productivity and chemical-bromatological composition were calculated in an Excel Worksheet using the t-test ($p = 0.05$) for the hypothesis testing on a non-zero correlation.

4 RESULTS

Analysis of variance indicated significant difference among the treatments ($P \leq 0.05$). Doses of 100 and 200 kg ha^{-1} of P lead to the highest LDM of the pasture (Table 2). The first one was about 66.32% higher than that observed for Pb, with over 2.60 Mg ha^{-1} no longer immediately available for animal consumption at 56 days of pasture growth. Nevertheless, one must consider that even Pnb (0 kg ha^{-1} P) produced an LDM around 28.64% higher than Pb.

Table 2

Means of leaf dry mass productivity, mean of phosphorus, magnesium, sulfur, manganese, iron in the leaf of *B. Brizantha*.

Treatment	Leaf dry mass productivity and phosphorus, magnesium, sulfur, manganese, iron					
	LDM	P	Mg	S	Mn	Fe
	Mg ha ⁻¹	g kg ⁻¹			mg kg ⁻¹	
Pnb	1.85 b	1.60 c	4.11 bc	0.617 c	77.6 bc	52.63 c
Pnb+25	2.01 b	1.85 bc	4.47 abc	0.630 c	67.98 c	52.30 c
Pnb+100	3.92 a	1.93 b	5.13 a	0.932 a	87.45 ab	61.25 b
Pnb+200	3.82 a	2.32 a	4.96 ab	0.830 ab	87.79 ab	48.92 c
Pb	1.32 c	2.14 ab	3.95 c	0.750 bc	98.83 a	193.58 a
LSD	0,285	0.318	0.959	0.236	0.0071	6,19
MS _{Residue}	0.016***	0.02***	0.018***	0.011***	44.287***	7.537***
CV (%)	4.78	7.17	9.40	13.92	7,93	3.36
C	0.513	0.548	0.285	0.590	0.385	0.455

Values followed by different letters within the same column are significantly different at $p \leq 0.05$ by the Tukey's multiple range test. MS_{Residue}: mean square residue. CV (%): coefficient of variation. C: Cochran's statistic. LSD: less significant difference of the Tukey's test. *: significant at 0.05 probability level, **: significant at 0.01 probability level, ***: significant at lesser than 0.01 probability level, NS: not significant.

The foliar concentration of P observed for the dose of 200 kg ha⁻¹ of P (Pnb+200) was statistically superior to the values provided by 100 kg ha⁻¹ of P (Pnb+100) and Pb practice, which did not differ from each other (Table 2). The highest concentrations of Mg and S were verified for 100 kg ha⁻¹ of P while the highest P dose provided superior Mn values that were nonetheless statistically similar to the Pb practice. In the case of Fe, the micronutrient appears in a very high and statistically superior concentration in the Pb treatment.

As expected on short-term assessments, the content of CP in this study was not altered by the treatments (F^{NS} , $p \leq 0.05$). The global mean of CP in the leaf of *B. brizantha* at 56 days was 8.23%. Higher percentage of ADF, NDF and Lignin was observed for treatments in which the pasture was not burned, with or without P application (Table 3).

In the Figure 2, one may observe that there were moderate and positive correlations between LDM and Fo-Mg and LDM with Fo-S, and a low and negative correlation between LDM and Fo-Fe. Fo-P presented low correlations with the structural carbohydrate concentrations of NDF and ADF besides Fo-Mn and Fo-S. Fo-Mg was low correlated to Lignin, Fo-Fe and Fo-S, which presented just a low correlation with the Lignin concentration. Fo-Mn was moderately and negatively correlated to NDF and ADF, and moderately and positively correlated with Fo-Fe. Fo-Fe, in turn, was highly and negatively correlated with the structural carbohydrates NDF and ADF and moderately and negatively correlated with Lignin. NDF sulfúur and a low correlation with the lignin and sulfur.

Table 3

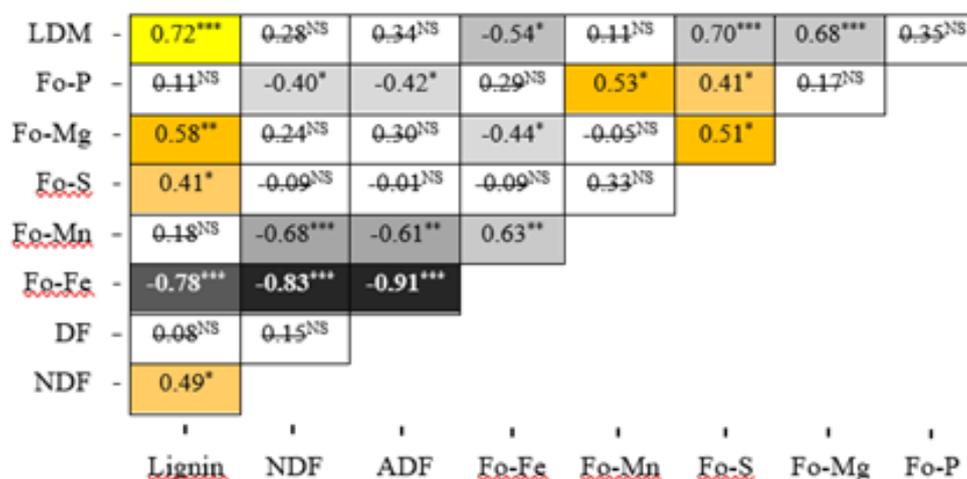
Means of acid detergent fiber (ADF), neutral detergent fiber (NDF) and lignine in the leaf of *B. Brizantha*.

Treatment	Acid detergent fiber, neutral detergent fiber and lignine		
	ADF	NDF	Lignine
	----- % -----		
Pnb	32.07 a	69.23 a	2.33 a
Pnb+25	31.90 a	68.69 a	2.13 b
Pnb+100	31.17 a	67.63 a	2.37 a
Pnb+200	31.43 a	68.27 a	2.41 a
Pb	28.45 b	64.30 b	1.92 c
LSD	1.483	2.70	0.504
MS _{Residue}	0.433 ^{***}	1434 ^{***}	0.030 ^{***}
CV (%)	2.12	1.77	3.24
C	0.415	0.560	0.431

Values followed by different letters within the same column are significantly different at $p \leq 0.05$ by the Tukey's multiple range test. MS_{Residue}: mean square residue. CV (%): coefficient of variation. C: Cochran's statistic. LSD: less significant difference of the Tukey's test. *: significant at 0.05 probability level, **: significant at 0.01 probability level, ***: significant at lesser than 0.01 probability level, ^{NS}: not significant.

Figure 2

Pearson's linear correlation coefficients between leaf productivity and chemical-bromatological composition variables of *B. Brizantha*



^{NS} non-significant; * significant ($p = 0.05$); ** significant ($p = 0.01$); *** significant ($p = 0.001$).

5 DISCUSSION

According to Mwendia *et al.* (2022), the productivity and quality of tropical pastures are among the basis for evaluating the capacity for feeding animals on cattle farming systems. In the present work, the statistically superior behaviour of LBM productivity observed for 100 kg ha⁻¹ of P (Pnb+100) validates this level of P fertilization as a possibility to increase the feed availability to animals in 56 days of pasture growth. Several authors observed an increase of biomass production, including leaf biomass, when P and other nutrient management is adopted in similar conditions (Aryal *et al.*, 2020; Souza *et al.*, 2020; Farias *et al.*, 2016;

Marahata *et al.*, 2014). Results reported by Porto *et al.* (2012) also agree with the present results. These authors verified 24% higher dry mass production on leaves of *B. brizantha* cv. Marandu with the dose of 147 kg ha⁻¹ of P₂O₅. These findings represent more available feed for the cattle compared to the burning treatment. Furthermore, this may constitute an encouragement for cattle breeders to adopt them as a technology for *B. brizantha* management and contribute to avoid the intensification of the negative environmental impacts reported by Rumpel *et al.* (2015) and Luizão *et al.* (2013) in the Brazilian Amazon livestock systems.

Furthermore, the LDM productivity levels observed for 0 and 25 kg ha⁻¹ of P lead to the statement that a mere suppression of the pasture burning, along with an agronomic dose of N and K, are an adequate management for better leaf availability compared to the use of fire. Other authors also observed results that agree with the present results under different experimental conditions (Dias *et al.*, 2015; Ieri *et al.*, 2010), including one whose methodology and results (Heringer; Jackes, 2002c) are very similar to the verifications made with this work. Regarding the economical concern, the use of P_{nb}+100 of P applied together with agronomic doses of N and K reduces the cost of production in relation to the dose of 200 kg ha⁻¹ of P. This is a fact simply because the similar LDM value observed for this treatment (Table 2) was obtained with twice the fertilizer material.

The results under discussion still showed that both P and S were within the sufficiency range for the normal growth of *Brachiaria* spp (Brasil *et al.*, 2020). The Mg concentration was above the species requirements according to the same authors. These facts are related to the presence of these nutrients on the composition of the PPR used as P source (Table 1). Therefore, an increase on the P dose from the PPR increases, concomitantly, the dose of these nutrients present on it. Similarly, Machado *et al.* (2011) also reported an increase of P concentration in leaf tissue of the studied pasture when increasing doses of soluble P were applied. It is also important to clarify that the nutrient P is important not only for plant growth, but also for the effective development of rumen microbes in ruminants (Satter *et al.*, 2005), among other functions in animal metabolism.

In relation to Mn and Fe, the values observed with the dose of 100 kg ha⁻¹ of P are in accordance with the normal values verified for *Brachiaria* spp. Leaf tissue (Brasil *et al.*, 2020) that vegetates on a normal growth condition. The adequacy to the pattern of requirements for *Brachiaria* spp. promoted by P fertilization is in contrast with the very high value of Fe concentration provided for the Pb treatment. The high quantity of this micronutrient on the burned pasture leaf may constitute a problem for high grazing quantities by the animals since

the chemical composition of the pasture must be coupled with an adequate quantity of pasture biomass production (Brâncio *et al.*, 1997).

According to Brasil *et al.* (2020), the global means of N (adequate), K (adequate), Ca (inadequate) concentrations on the leaf tissue of *Brachiaria* spp., respectively, of 12.2, 17.2, 2.38 g kg⁻¹ did not limit pasture growth and leaf productivity at the 56-day mark. The global concentrations of B, Cu and Zn were, respectively, 4.44, 3.52 and 12.5 mg kg⁻¹ (F^{NS}, p≤0.05) and are below the pasture requirements according to the same reference. So, it is possible to affirm, for a short-term evaluation in discussion, that pasture fertilization with 100 kg ha⁻¹ of P improves the chemical composition for important nutrients that occur in low availability in acidic soils (Campos *et al.*, 2012) under livestock systems in the southwestern Amazon.

It is pertinent at this time to point out that, for many authors, the critical values for pasture growth may be different from the animal requirements for mineral elements. It is also clear that for P, Ca, Mg and most of the micronutrients, the cattle requirements exceed the plant requirements, with the exception of K. Anyway, the difference between nutrient availability in leaf tissue and animal needs is balanced by the adequate amount of LDM made available by the dose 100 kg ha⁻¹ of P. These findings are thus very important, since one can state that the foliar nutrient concentrations observed in this work were not limitant factors neither for pasture growth nor for their use on animal feed at 56 days of pasture growth.

All the doses of P without pasture burning presented statistically superior values of ADF compared to Pb (Table 2). In turn, all the treatments without burning, with or without P application, promoted statistically superior values of NDF contents, which showed to be ever higher than 65%. A similar behaviour was observed for lignin, with statistically superior values for treatments with P application compared to the Pb treatment.

The results exposed in Table 2 indicate a more soluble and digestible cellular content for animal consumption. Nevertheless, all values were framed slightly below the appropriate values for proper digestibility and consumption by ruminants, as reported by Van Soest (1994). The NDF values above 65% indicate a contribution to the reduction of the nutritional value of the leaf lamina of the pasture. Similar behaviour was verified for the lignin content in the leaf blade (Table 2), with values shown to be statistically superior in the treatments without burning, with or without P application. According to Jung *et al.* (1993) the process of lignification in plant cell walls has been considered an impediment to forage digestibility. According to Echeverria *et al.* (2016), the fact may be attributed to a reduced production of new leaves and the senescence of the old leaves in the start of the rainy season in the Amazon. That fact concomitantly causes a reduction of the cell contents and an increase of carbohydrates and lignin contents, decreasing the nutritional value of the pasture leaf.

The ADF contents in the leaf of *B. brizantha* observed in this study are next to a limiting range of consumption and the NDF contents are below it, including in the Pb treatment. These observations indicate that these contents are more related to physiological and structural characteristics of *B. brizantha* cv. 'Marandu' than to the supply of P or N and K fertilizations.

In relation to CP, the global mean observed of 8.23% is a desirable value for ruminant feed (for example) since a CP percentage below 7% leads to a lower forage digestion (Van Soest, 1994). According to Detmann *et al.* (2014), values of digestibility of *B. brizantha* cv. 'Marandu' are generally adequate as an animal feed. The values described here are not limiting to feed animals like ruminants (Van Soest, 1994) even within a short observation timeframe (56 days). On the other hand, Fischer *et al.* (1996) concluded that small increments on the nutritional value of pastures produced under the effects of fires occur occasionally. Other authors have observed improvements in the nutritional value, especially on the CP and digestible biomass production on different but recently burned pastures (Boughton *et al.*, 2022; Scasta *et al.* 2016; McGranahan *et al.*, 2014).

An extensive review indicates that the best alternative for eliminating pasture burning is the use of pasture improvement with the introduction of adequate management that prioritizes the maintenance of pasture sustainability (Zanini; Sbrissia, 2013). From a practical standpoint, animals kept in areas of burned pastures compared to unburned areas showed no difference in productive performance (Brâncio *et al.*, 1997).

The main relationships between LDM Productivity and chemical leaf composition indicate joint behaviour that avoids the pasture productivity normally occurring by the 56th day of growth. That fact is particularly confirmed by the adequate concentrations of P, Mg and S (Brasil *et al.*, 2020), which presented clear relationships among each other that influence the pasture's LDM productivity. The lignin concentration, in turn, increased on the leaf tissue as far as the LDM productivity concomitantly also increased. That verification, coupled with the high and negative associations among the structural carbohydrates and Fo-Fe likely denote the influence of Fe absorption on lignin, ADF and NDF contents on the leaf of *B. brizantha*, but without drastically reducing the leaf value as feed for grazing animals.

Despite that, pasture fertilization with 100.0 kg ha⁻¹ of P provided more leaves available for animal consumption in relation to the burning application, and makes the agroecosystem more sustainable on the agronomic, economic and environmental point of view.

6 CONCLUSION

The dose of 100 kg ha⁻¹ of phosphorus from the partially acidulated phosphate rock applied to unburned *B. brizantha* compared to the burnt version promoted: i) the highest leaf

blade dry mass productivity; ii) mineral nutrient concentrations not limitant to the pasture leaf productivity or to the leaf quality for animal consumption, and; iii) values of acid detergent fiber, neutral detergent fiber, lignin and crude protein means that indicate an adequate bromatological composition, which means high animal consumption of the leaf blade of *Brachiaria brizantha* cv. Marandu. We recognize the limitations of this work regarding the short time of observations, and mainly because other variables of nutritional value should be analysed for a more complete evaluation.

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REFERENCES

- AOAC. (1990). Official methods of analysis (15th ed.). Association of Official Analytical Chemists.
- Aryal, J. P., Rahut, D. B., Sapkota, T. B., & et al. (2020). Climate change mitigation options among farmers in South Asia. *Environment, Development and Sustainability*, 22, 3267–3289. <https://doi.org/10.1007/s10668-019-00414-4>
- Baggio, R., Overbeck, G. E., Durigan, G., & Pillar, V. D. (2021). To graze or not to graze: A core question for conservation and sustainable use of grassy ecosystems in Brazil. *Perspectives in Ecology and Conservation*, 19(3), 256–266. <https://doi.org/10.1016/j.pecon.2021.06.002>
- Boughton, E. H., Gomez-Casanovas, N., Swain, H., Bernacchi, C., Boughton, R. K., Brinsko, K., Li, H., Rivero, A., Delucia, E. H., & Sparks, J. (2022). Patch-burn grazing impacts forage resources in subtropical humid grazing lands. *Rangeland Ecology & Management*, 84(1), 10–21. <https://doi.org/10.1016/j.rama.2022.05.004>
- Brâncio, P. A., Nascimento Júnior, D., Moraes, E. A., Regazzi, A. J., & Leite, G. C. (1997). Avaliação de pastagem nativa dos cerrados submetida à queima anual. 2. Qualidade da dieta de bovinos. *Revista Brasileira de Zootecnia*, 26(3), 438–442.
- Brasil. (2020). Recomendações de calagem e adubação para o estado do Pará. Empresa Brasileira de Pesquisa Agropecuária. <https://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1125022>
- BRASIL. (2014). Manual de métodos analíticos oficiais para fertilizantes minerais, orgânicos, organominerais e corretivos (M. C. M. Veras, Org.). Ministério da Agricultura, Pecuária e Abastecimento. https://www.gov.br/agricultura/pt-br/assuntos/lfd/a/arquivos-publicacoes-laboratorio/manual_in-5_analiticos-oficiais-para-fertilizantes-e-corretivos_com_capa_final_03.pdf

- Campos, M. C. C., Ribeiro, M. R., Souza Junior, V. S., Ribeiro Filho, M. R., & Almeida, M. C. (2012). Topossequência de solos na transição Campos Naturais-Floresta na região de Humaitá, Amazonas. *Acta Amazônica*, 42(3), 387–398. <https://doi.org/10.1590/S0044-59672012000300011>
- Cardoso, E. L., & Crispim, S. M. A. (2003). Efeitos da queima na produção e valor nutritivo da matéria seca em área de *Andropogon bicornis* (Boletim 50). Embrapa Pantanal. <https://queimadas.dgi.inpe.br/~rqueimadas/material3os/BP50.pdf>
- Cayley, J. W. D., & Bird, P. R. (1996). Techniques for measuring pastures. Pastoral and Veterinary Institute.
- Conant, R. T. (2010). Challenges and opportunities for carbon sequestration in grassland systems: A technical report. *Integ Crop Manag.* <https://www.fao.org/3/i1399e/i1399e00.pdf>
- Detmann, E., Valente, E. E. L., Batista, E. D., & Huhtanen, P. (2014). An evaluation of the performance and efficiency of nitrogen utilization in cattle fed tropical grass pastures with supplementation. *Livestock Science*, 162, 141–153. <https://doi.org/10.1016/j.livsci.2014.01.029>
- Dias, D. G., Pegoraro, R. F., Alves, D. D., Porto, E. M., Santos Neto, J. A., & Aspiazú, I. (2015). Produção do capim Piatã submetido a diferentes fontes de fósforo. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 19, 330–335. <https://doi.org/10.1590/1807-1929/agriambi.v19n4p330-335>
- Dias-Filho, M. B. (2011b). Degradação de pastagens: Processos, causas e estratégias de recuperação. Embrapa Amazônia Oriental. <https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1070416/1/TC1117CartilhaPastagemV04.pdf>
- Dias-Filho, M. B. (2014b). Diagnóstico das pastagens no Brasil. Embrapa Amazônia Oriental. <https://www.infoteca.cnptia.embrapa.br/bitstream/doc/986147/1/DOC402.pdf>
- Dick, D. P., Martinazzo, R., Dalmolin, R., Jacques, A. V. A., Mielniczuk, J., & Rosa, A. S. (2008). Impacto da queima nos atributos químicos e na composição química da matéria orgânica do solo e na vegetação. *Pesquisa Agropecuária Brasileira*, 43, 633–640. <https://www.scielo.br/j/pab/a/wxL86vcqs4vww8PVJfQZQYw/?format=pdf&lang=pt>
- Echeverria, J. R., Euclides, V. P. B., Sbrissia, A. F., Montagner, D. B., Barbosa, R. A., & Nantes, N. N. (2016). Forage accumulation and nutritive value of the *Urochloa* interspecific hybrid 'BRS RB331 Ipyporã' under intermittent grazing. *Pesquisa Agropecuária Brasileira*, 51(7), 880–889. <https://doi.org/10.1590/S0100-204X2016000700011>
- EMBRAPA. (1997). Manual de métodos de análises de solo (2nd ed.). Ministério da Agricultura e do Abastecimento. <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/169149/1/Manual-de-metodos-de-analise-de-solo-2-ed-1997.pdf>
- Farias, S. C. C., Júnior, S., Ruivo, M. D. L. P., Rodrigues, P. G., Melo, V. S. D., Costa, A. D. R., & Souza Júnior, J. C. D. (2016). Phosphorus forms in Ultisol submitted to burning and trituration of vegetation in Eastern Amazon. *Revista Brasileira de Ciência do Solo*, 40, Article e0150198. <https://www.scielo.br/j/rbcs/a/HNBfpn8r9HB7VxZMzRVFWLD/?lang=en&format=pdf>

- Fischer, M. J., et al. (1996). Grasslands in the well watered tropical lowlands. In J. Hodgson & A. W. Illius (Eds.), *The ecology and management of grazing systems* (pp. 418–419). CAB International.
- Gerber, P. J., Henderson, B., & Makkar, H. P. (2013a). Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO₂ emissions. FAO. <https://www.fao.org/3/i3288e/i3288e.pdf>
- Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Faluccci, A., & Tempio, G. (2013b). Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities. FAO. <https://www.fao.org/3/i3437e/i3437e.pdf>
- Girona-García, A., Galarza, R. Z., Mora, J. L., Armas-Herrera, C. M., Martí, C., Ortiz-Perpiñá, O., & Badía-Villas, D. (2018). Effects of prescribed burning for pasture reclamation on soil chemical properties in subalpine shrublands of the Central Pyrenees (NE-Spain). *Science of the Total Environment*, 644, 583–593. <https://doi.org/10.1016/j.scitotenv.2018.06.363>
- Heringer, I., & Jacques, A. V. A. (2002c). Nutrientes no mantillo em pastagem nativa sob distintos manejos. *Ciência Rural*, 32, 841–847. <https://doi.org/10.1590/S0103-84782002000500016>
- Hopkins, B. G., & Hansen, N. C. (2019). Phosphorus management in high-yield systems. *Journal of Environmental Quality*, 48, 1265–1280. <https://doi.org/10.2134/jeq2019.03.0130>
- leiri, A. Y., Lana, R. M. P., Korndörfer, G. H., & Pereira, H. S. (2010). Fontes, doses e métodos de aplicação de fósforo na recuperação de pastagem com *Brachiaria*. *Ciência e Agrotecnologia*, 34, 1154–1160. <https://doi.org/10.1590/S1413-70542010000500011>
- IPCC. (2014). *Climate change 2014: Mitigation of climate change*. In O. Edenhofer et al. (Eds.), *Contribution of Working Group III to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_frontmatter.pdf
- Jung, H. G., & Deetz, D. A. (1993). Cell wall lignification and degradability. In H. G. Jung, D. R. Buxton, R. D. Hatfield, & J. Ralph (Eds.), *Forage cell wall structure and digestibility*. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.
- Lal, R. (2011). Soil carbon sequestration. In *Solaw: Background thematic report tr04b. The state of the world's land and water resources*. Food and Agriculture Organisation of the United Nations. https://www.fao.org/fileadmin/templates/solaw/files/thematic_reports/TR_04b_web.pdf
- López-Mársico, L., Farías-Moreira, L., Lezama, F., Altesor, A., & Rodríguez, C. (2019). Light intensity triggers different germination responses to fire-related cues in temperate grassland species. *Folia Geobotanica*, 54(1), 53–63. <https://doi.org/10.1007/s12224-019-09336-5>
- Luizão, F. J., Fearnside, P. M., Cerri, C. E. P., & Lehmann, J. (2013). The maintenance of soil fertility in Amazonian managed systems (pp. 311–336). In M. Keller, M. Bustamante, J. Gash, & P. Da Silva (Eds.), *Amazonia and global change (Geophysical Monograph Series, Vol. 186)*. American Geophysical Union. <https://repositorio.inpa.gov.br/handle/1/35281>
- Machado, V. J., Souza, C. H. E., Andrade, B. B., Lana, R. M. Q., & Korndörfer, G. H. (2011). Curvas de disponibilidade de fósforo em solos com diferentes texturas após aplicação

de doses crescentes de fosfato monoamônico. *Bioscience Journal*, 27, 70–76. <https://seer.ufu.br/index.php/biosciencejournal/article/view/7389/6843>

Machado, L. A. Z., & Valle, C. B. (2011). Desempenho agrônomo de genótipos de capim-braquiária em sucessão à soja. *Pesquisa Agropecuária Brasileira*, 46, 1454–1462. <https://doi.org/10.1590/S0100-204X2011001100006>

Magalhães, A. F., Pires, A. J. V., Carvalho, G. D., Silva, F. D., Sousa, R. S., & Veloso, C. M. (2007). Influência do nitrogênio e do fósforo na produção do capim braquiária. *Revista Brasileira de Zootecnia*, 36(5), 1240–1246. <https://doi.org/10.1590/S1516-35982007000600004>

Marahata, S., Sah, S. K., MacDonald, A., Timilnisa, J., & Devkota, K. P. (2014). Influence of conservation agriculture practices on physical and chemical properties of soil. *International Journal of Advanced Research*, 2, 43–52. https://www.journalijar.com/uploads/638_IJAR-4425.pdf

McGranahan, D. A., Henderson, C. B., Hill, J. S., Raicovich, G. M., & Wilson, W. N. (2014). Patch burning improves forage quality and creates grass-bank in old-field pasture: Results of a demonstration trial. *Southeastern Naturalist*, 13, 200–207. <https://doi.org/10.1656/058.013.0203>

Mottet, A., Henderson, B., Opio, C., Falcucci, A., Tempio, G., Silvestri, S., & Chesterman, S. (2017). Climate change mitigation and productivity gains in livestock supply chains: Insights from regional case studies. *Regional Environmental Change*, 17, 129–141. <https://doi.org/10.1007/s10113-016-0986-3>

Moxley, J., Steven, G. A., Anthony, K. B., & et al. (2014). Capturing cropland and grassland management impacts on soil carbon in the UK LULUCF inventory. 90 p. <https://nora.nerc.ac.uk/id/eprint/508474/1/N508474CR.pdf>

Mwendia, S. W., Ohmstedt, U., Nyakundi, F., Notenbaert, A., & Peters, M. (2022). Does harvesting *Urochloa* and *Megathyrsus* forages at short intervals confer an advantage on cumulative dry matter yields and quality? *Journal of the Science of Food and Agriculture*, 102(2), 750–756. <https://doi.org/10.1002/jsfa.11407>

Pequeno, D. N. L., Pedreira, L. E., Sollenberger, L. E., & Silva, L. S. (2015). Forage accumulation and nutritive value of brachiaria grasses and Tifton 85 bermuda grass as affected by harvest frequency and irrigation. *Agronomy Journal*, 107, 1741–1749. <https://doi.org/10.2134/agronj15.0115>

Porto, E. M. V., Alves, D. D., Vitor, C. M. T., Gomes, V. M., Silva, M. F., & VID, A. M. S. S. R. (2012). Rendimento forrageiro da *Brachiaria brizantha* cv. Marandu submetida a doses crescentes de fósforo. *Scientia Agraria Paranaensis*, 11(3), 25–34. <https://doi.org/10.5380/agraria.v11i3.XXXX> [Nota: DOI parece incorrecto en el original; usa el proporcionado pero verifica si es el correcto para el journal]

Raij, B. van, Andrade, J. C., Cantarella, H., & Quaggio, J. A. (2001). Análise química para avaliação da fertilidade de solos tropicais. IAC.

Rumpel, C., Crème, A., Ngo, P. T., Velásquez, G., Mora, M. L., & Chabbi, A. (2015). The impact of grassland management on biogeochemical cycles involving carbon, nitrogen and phosphorus. *Journal of Soil Science and Plant Nutrition*, 15, 353–371. <https://doi.org/10.4067/S0718-95162015005000034>

Santos, H. G., Jacomine, P. K. T., Dos Anjos, L. H. C., Oliveira, V. A., et al. (2018). Sistema Brasileiro de Classificação de Solo (5th ed., rev. and ampl.). Embrapa. <https://www.infoteca.cnptia.embrapa.br/handle/doc/1094003>

- Scasta, J. D., Thacker, E. T., Hovick, T. J., Engle, D. M., Allred, B. W., Fuhlendorf, S. D., & Weir, J. R. (2016). Patch-burn grazing (PBG) as a livestock management alternative for fire prone ecosystems of North America. *Renewable Agriculture and Food Systems*, 31, 550–567. <https://doi.org/10.1017/S1742170515000411>
- Silva, F. C. (2009). *Manual de análises químicas de solos, plantas e fertilizantes* (2nd ed.). Embrapa Informação Tecnológica; Embrapa Solos. <https://www.infoteca.cnptia.embrapa.br/handle/doc/330496>
- Silva, V. J., Pedreira, L. E., Sollenberger, L. S. S., & Yasuoka, I. C. L. A. (2016b). Carbon assimilation, herbage plant-part accumulation, and organic reserves of grazed 'Mulato II' brachiariagrass pastures. *Crop Science*, 56, 2853–2860. <https://doi.org/10.2135/cropsci2016.03.0148>
- Sollenberger, L. E., Kohmann, M. M., Dubeux, J. C. B., & Silveira, M. L. (2019). Grassland management affects delivery of regulating and supporting ecosystem services. *Crop Science*, 59, 441–459. <https://doi.org/10.2135/cropsci2018.09.0594>
- Satter, L. D., Klopfenstein, T. J., Erickson, G. E., Galen, E. J., & Mark Powell, J. M. (2005). Phosphorus and dairy/beef nutrition. University of Nebraska, Faculty Papers and Publications in Animal Science, 549.
- Souza, J. G., Aires, F. P. G., Gomide, P. H. O., & Nunes, J. C. (2020). Calagem e adubação no crescimento do capim mombaça em Roraimópolis, Roraima. *Revista Ambiente: Gestão e Desenvolvimento*, 13(1). <https://doi.org/10.24979/376>
- Soussana, J. F., & Lemaire, G. (2014). Coupling carbon and nitrogen cycles for environmentally sustainable intensification of grasslands and crop-livestock systems. *Agriculture, Ecosystems & Environment*, 190, 9–17. <https://doi.org/10.1016/j.agee.2013.10.012>
- Van Der Werf, G. R., Randerson, J. T., Giglio, L., Gobron, N., & Dolman, A. J. (2008). Climate controls on the variability of fires in the tropics and subtropics. *Global Biogeochemical Cycles*, 22(3), Article GB3028. <https://doi.org/10.1029/2007GB003122>
- Van Soest, P. J. (1994). *Nutritional ecology of the ruminant* (2nd ed.). Cornell University Press.
- Vetter, S. H., Sapkota, T. B., Hillier, J., Stirling, C. M., Macdiarmid, J. I., Aleksandrowicz, L., et al. (2017). Greenhouse gas emissions from agricultural food production to supply Indian diets: Implications for climate change mitigation. *Agriculture, Ecosystems & Environment*, 237, 234–241. <https://doi.org/10.1016/j.agee.2016.12.024>
- Zanini, G. D., & Sbrissia, A. F. (2013). Fogo em pastagens: Estratégia de manejo? *Revista de Ciências Agroveterinárias*, 12(1), 94–103. <https://revistas.udesc.br/index.php/agroveterinaria>