



PHOSPHATE FERTILIZATION WITHOUT PASTURE BURNING INCREASE BIOMASS PRODUCTIVITY AND REDUCE CARBON LOSS

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ABSTRACT

Objective: In this work we evaluate the phosphorus fertilization without burning on the biomass productivity and the reduction of carbon loss from the pasture of *Brachiaria brizantha* in the Brazilian Amazon.

Theoretical Framework: *Brachiaria brizantha* is the main cultivated pasture species in Brazil. The overgrazing and no nutrient replenishment in addition to the periodical burnings are the trigger factors of a gradual degradation since the 70's in the Amazon. That fact suggests the need for research solutions to eliminate the use of this practice for pasture management.

Method: A field experiment was carried out from September to November 2015 in a completely randomized blocks design. The treatments consisted of unburned pasture treated with 0, 25, 100 and 200 kg ha⁻¹ of phosphorus compared to the pasture burning, with 4 blocks and 20 experimental plots. The experimental plots treated with phosphorus received agronomic doses of potassium and nitrogen applied on the soil surface. After applying the treatments, including the burning, the pasture was desiccated in order to homogenize the plant emergence and growth after the period without rain from July to September.

Results and Discussion: The soil fertility attributes, components of biomass productivity, partial carbon stocks and the partial carbon retained in the pasture (not lost as carbon dioxide) were quantified at 56 days after the beginning of the experimental period. In comparison to the pasture burning, the treatments alter the soil phosphorus availability and, as a result, increase the partial biomass productivity and its carbon content, reducing the loss of carbon dioxide to the atmosphere.

Research Implications: 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 in order to supply phosphorus for *B. brizantha* instead of using fire as a strategy of pasture management.

Originality/Value: This study contributes to the literature by highlighting the superiority of phosphorus application from alternative source 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: Phosphorus, Amazon, Fire, *Brachiaria spp.*

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ADUBAÇÃO FOSFATADA SEM QUEIMA DA PASTAGEM AUMENTA A PRODUTIVIDADE DE BIOMASSA E REDUZ PERDA DE CARBONO

RESUMO

Objetivo: Neste trabalho avaliamos a adubação fosfatada sem a queimada na produtividade de biomassa e na redução da perda de carbono do pasto de *Brachiaria brizantha* na Amazônia brasileira.

Referencial Teórico: A *Brachiaria brizantha* é a principal espécie de pastagem cultivada no Brasil. O sobrepastoreio e a não reposição de nutrientes além das queimadas periódicas são os desencadeadores da degradação dessas pastagens desde a década de 70 na Amazônia. Estes fatos sugerem necessidade de soluções de pesquisas para eliminar essa prática para manejo das pastagens.

Método: Um experimento de campo foi realizado de setembro a novembro de 2015 em delineamento em blocos casualizados. Os tratamentos consistiram da pastagem não queimada tratada com 0, 25, 100 e 200 kg ha⁻¹ de fósforo comparados à pastagem queimada, com 4 blocos e 20 parcelas experimentais. As parcelas experimentais tratadas com fósforo receberam doses de potássio e nitrogênio aplicadas na superfície do solo. Após a aplicação dos tratamentos, incluída a queimada, o pasto foi dissecado com o objetivo de homogeneizar a emergência de plantas após o período sem chuvas de julho a setembro.

Resultados e Discussão: Os atributos de fertilidade do solo, componentes da produtividade de biomassa, estoques parciais de carbono e o carbono parcial retido (não perdido na forma de dióxido) foram quantificados aos 56 dias após o início do período experimental. Os tratamentos alteraram a disponibilidade de fósforo no solo e, como consequência, aumentaram a produtividade de biomassa parcial atual e seu teor de carbono, reduzindo a perda de dióxido de carbono para a atmosfera.

Implicações da Pesquisa: As implicações práticas e teóricas desta pesquisa são discutidas, provendo percepções sobre como os resultados podem ser aplicados ou influenciar práticas no campo do manejo da pastagem sem uso do fogo. Estas implicações podem abranger como aplicar e quanto aplicar de um fosfato alternativo deve ser aplicado ao solo de modo a suprir fósforo para *B. brizantha* ao invés de usar o fogo como uma estratégia de manejo da pastagem.

Originalidade/Valor: Este estudo contribui com a literatura por destacar a superioridade da aplicação de fósforo de fonte alternativa aliado à fertilização com N e K comparada à prática da queimada da pastagem no Sudoeste da Amazônia. Esta abordagem inovativa pode ser usada como uma base para novas pesquisas e aplicada em nível de produtores de gado.

Palavras-chave: Fósforo, Amazônia, Fogo, *Brachiaria spp.*

LA FERTILIZACIÓN COM FOSFATO SIN QUEMAR PASTOS AUMENTA LA PRODUCTIVIDAD DE LA BIOMASA Y REDUCE LA PÉRDIDA DE CARBONO

RESUMEN

Objetivo: Em este trabajo evaluamos la fertilización fosfatada sin quema sobre la productividad de la biomasa y la reducción de la pérdida de carbono del pastizal de *Brachiaria brizantha* em la Amazonía Brasileña.

Marco Teórico: *Brachiaria brizantha* es la principal especie de pasto cultivada em Brasil. El pastoreo excesivo y la falta de reposición de nutrientes, además de los incendios periódicos, son los desencadenantes de la degradación de estos pastos desde los años 1970 em el Amazonas. Estos hechos sugieren la necesidad de investigar soluciones para eliminar esta práctica em el manejo de pastos.

Método: Se realizó um experimento de campo de septiembre a noviembre de 2015 em um diseño de bloques al azar. Los tratamientos consistieron em pasto no quemado tratado com 0, 25, 100 y 200 kg há⁻¹ de fósforo frente a pasto quemado, com 4 bloques y 20 parcelas experimentales. Las parcelas experimentales tratadas com fósforo recibieron dosis de potasio y nitrógeno aplicados a la superficie del suelo. Luego de aplicar los tratamientos, incluída la quema, se diseccionó el pasto com el objetivo de homogeneizar la emergencia de las plantas luego del período sin lluvias de julio a septiembre.



Resultados y Discusión: Los atributos de fertilidad del suelo, los componentes de la productividad de la biomasa, las reservas parciales de carbono y el carbono parcial retenido (no perdido en forma de dióxido) se cuantificaron 56 días después del inicio del período experimental. Los tratamientos alteraron la disponibilidad de fósforo en el suelo y, como consecuencia, aumentaron la productividad parcial actual de la biomasa y su contenido de carbono, reduciendo la pérdida de dióxido de carbono a la atmósfera.

Implicaciones de la Investigación: Se discuten las implicaciones prácticas y teóricas de esta investigación, proporcionando información sobre cómo los resultados pueden aplicarse o influir en las prácticas en el campo del manejo de pastos libres de incendios. Estas implicaciones pueden incluir cómo aplicar y qué cantidad de un fosfato alternativo se debe aplicar al suelo para suministrar fósforo a *B. brizantha* en lugar de utilizar el fuego como estrategia de manejo de pastos.

Originalidad/Valor: Este estudio contribuye a la literatura destacando la superioridad de la aplicación de fósforo de una fuente alternativa combinado con fertilización con N y K en comparación con la práctica de quema de pastos en el suroeste amazónico. Este enfoque innovador puede utilizarse como base para futuras investigaciones y aplicarse a nivel de productores ganaderos.

Palabras clave: Fósforo, Amazonas, Fuego, *Brachiaria* spp.

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1 INTRODUCTION

Brachiaria brizantha is the main species of cultivated pasture in the Brazilian Amazon. The overgrazing and no nutrient replenishment (Dias-Filho, 2014b) besides the periodical burnings are the triggering of its degradation since the 70's. The lack of credit to the cattle breeders limits the adoption of technical knowledge of using fertilizer materials to recover the soil fertility to increase the biomass productivity to contribute for mitigating the main problem derived from the GHG emissions (Aryal *et al.*, 2020) in the Amazon region. That situation leads to the continuous use of fire as a strategy for managing *B. brizantha* vegetating on uncovered and nutrient leaching and water erosion degraded soils, showing to be unproductive and overrun by weeds.

There is a lack of information about biomass productivity and C retention on not burned pasture under the effects of phosphate fertilization compared to the periodical burning on the Amazon livestock agroecosystems. For that reason, we evaluate the effects of phosphorus fertilization without pasture burning on the biomass productivity and the reduction of carbon loss from the *Brachiaria brizantha* agroecosystem in the Brazilian Amazon.



2 THEORETICAL FRAMEWORK

The negative effects of the periodical fire using on pastures in the Southwestern Amazon are notorious. According to Luizão *et al.* (2013), losses about 96%, 47% and 48%, respectively, for nitrogen (N), phosphorus (P) and potassium (K) stored in the biomass have been related to the burnings. As a result, the problems related to the greenhouse gas (GHG) emissions emerged from a wide area.

Biomass burning also releases carbon (C) as dioxide (CO₂), monoxide (CO) and methane (CH₄), and gaseous N to the atmosphere and nitrate (NO₃⁻) to the soil (Rumpel *et al.*, 2015). About 98% of the C losses from the biomass is caused by burnings (Luizão *et al.*, 2013). In turn, the soil organic carbon (SOC) varies from 5% to 45% in soils under effects of biomass burning (Rodionov *et al.*, 2010). That large variation has been attributed to the C inputs that depends on the biomass production of the pastures (Yao *et al.*, 2010).

Literature indicates that pasture burning additionally improves the soil P availability (Tomasi *et al.*, 2012), that remains high for longer periods (Faria *et al.*, 2011). Dick *et al.* (2008) reported increase of the soil pH, basis saturation (V%), exchangeable calcium (Ca²⁺), magnesium (Mg²⁺) and potassium (K⁺) as well as cation exchange capacity (CEC), but just in a short period after the fire application.

On the other hand, the major issue concerning pasture biomass productivity is the low P availability, especially in soils with high acidity (Oliveira *et al.*, 2011), such as in the southwestern Amazon. For that reason, the pasture phosphate fertilization without biomass burning has been a way to increase P availability and the biomass productivity and C stocks of different cultivated pasture species (Aryal *et al.*, 2020; Souza *et al.*, 2020; Farias *et al.*, 2016; *et al.*, 2015; Marahata *et al.*, 2014).

Inputs on leaf biomass has been pointed as a potential reducer of GHG emissions by increasing the C retention (and not lost) on livestock systems, that are responsible for 14.5% of the total C emissions by human activities (Mottet *et al.*, 2017; Vetter *et al.*, 2017; IPCC, 2014; Gerber *et al.*, 2013a, b). The increase of biomass productivity means pasture restoration and more available feed for cattle and, for that reason, according to the widely used method for calculating (Das Virgens *et al.*, 2020), it has been considered synonymous of reducing the GHG emissions and a strategy for mitigating the global climate change (Lal, 2011; Conant, 2010).



3 MATERIAL AND METHODS

3.1 EXPERIMENTAL AREA

A field experiment comprised by the *B. brizantha* not burned and fertilized with four dosis of P compared to the simple pasture burning was performed from September to November 2015 at the Vanazzi's Cattle Farm, BR 319, km 12, on a transition Amazon forest-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 (Köppen), with a rainy season from setember to july, mean air temperature of 26.5 °C, total rainfall of 2500 mm and a relative humidity between 85 to 90% (Vidotto *et al.*, 2007).

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 grass, at the stage II of degradation according to Dias-Filho (2011b). The pasture was not burned or grazed from September 2014 to September 2015. A manual weeding of weeds in September 2014 made that practice unnecessary in 2015, since the rapid pasture growth covered the soil and suppressed a 100% of these plants.

3.2 EXPERIMENT ESTABLISHMENT

For the establishment of blocks and plots, a homogeneous cutting with garden shears levelled the pasture at a 0.20 m height on 07/23/2015, in order to simulate the traditional Amazon grazing of a hundred percent of the pasture leaf area on the experimental area. And then, a representative sample (from fifteen simple samples) of the biomass at the soil surface (leaf blade + leaf sheath + dry stalks + emerged tillers + litter biomass) was collected with a 0.0415 m² jig after cutting close to the ground with a garden shears. Then, the sample was placed on a 0.18 m x 0.36 m paper bags and dried at a forced air oven (*Tecnal TE-394/5-MP*, Piracicaba, Brazil) at 67 °C for 72 h in order to obtain the initial surface biomass quantification of the *B. brizantha* (g m⁻²), by weighing at a precision scale (*Tecnal, SHI-BL-3200H*, Piracicaba, Brazil), prior to the experiment. Subsequently, that biomass was dried at the same forced air oven at 105 °C for 24 hours in order to estimate 3.21 Mg ha⁻¹ of litter biomass, prior to the experiment. That biomass corresponds to 1.45 Mg ha⁻¹ of C or 5.30 Mg ha⁻¹ of CO₂, calculated by multiplying the dry biomass by the factor 0.45 (IPCC, 2006).

On 09/12/2015 the blocks were established at a subareas in the experimental area. The plots measured 4.50 m long by 3.50 m wide (15.75 m²) and 0.80 m in the borders (Cayley and



Bird, 1996). Plots delimitation were made 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 experimental 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 chemical and physical analysis, prior to the experiment.

The topsoil presented (Silva, 2009): pH (water) = 5.00, $\text{Al}^{3+} = 1.02 \text{ cmol}_c \text{ dm}^{-3}$, $\text{H}+\text{Al} = 5.00 \text{ cmol}_c \text{ dm}^{-3}$, $\text{Ca}^{2+} = 2.01 \text{ cmol}_c \text{ dm}^{-3}$, $\text{Mg}^{2+} = 1.50 \text{ cmol}_c \text{ dm}^{-3}$, $\text{K}^+ = 0.09 \text{ cmol}_c \text{ dm}^{-3}$, $\text{CEC} = 8.33 \text{ cmol}_c \text{ dm}^{-3}$, $\text{SB} = 4.50 \text{ cmol}_c \text{ dm}^{-3}$, $\text{P (Mehlich-1)} = 3.0 \text{ mg dm}^{-3}$, $\text{V} = 42\%$, $\text{m} = 8.75\%$, $\text{SOC} = 11.36 \text{ g kg}^{-1}$, $\text{Cu}^{2+} = 4.25 \text{ mg dm}^{-3}$, $\text{Fe} = 297.59 \text{ mg dm}^{-3}$, $\text{Mn}^{2+} = 8.02 \text{ mg dm}^{-3}$, $\text{Zn} = 2.29 \text{ mg dm}^{-3}$. A 0.20 kg topsoil subsample were analyzed for: $\text{B (hot water)} = 0.08 \text{ mg dm}^{-3}$, and $\text{SO}_4^{2-} = 9.0 \text{ mg dm}^{-3}$ (Raij et al. 2001). The topsoil presented 7.44 Mg ha⁻¹ of partial carbon stock (topsoil CSt) (Veldkamp, 1994) of 7.44 Mg ha⁻¹, calculated based on the SOC, prior to the experiment. The topsoil presented a soil density (Sd) of 1.31 kg dm⁻³ (mean of 3 replicates) and: sand = 349.7, silt = 452.15 and clay = 181.87 g kg⁻¹ (Embrapa, 1997).

3.3 ESTABLISHMENT OF TREATMENTS

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 burned pasture, represented by Pb = burning of *B. brizantha*, with 4 replicates. The chemical and granulometry characteristics (MAPA, 2014) of the partially acidulated phosphate rock (PPR) used as the P source are in Table 1.

Doses of P were applied on 09/14/2015, after a rainfall higher than 2.0 mm (Figure 1a) by manual and homogeneously distribution of 0.0, 0.22, 0.88 and 1.76 kg plot⁻¹ of PPR, dry mass, to the surface of the plots for supply, 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 for nylon threads relocated to the end of the vertically fixed iron bars.

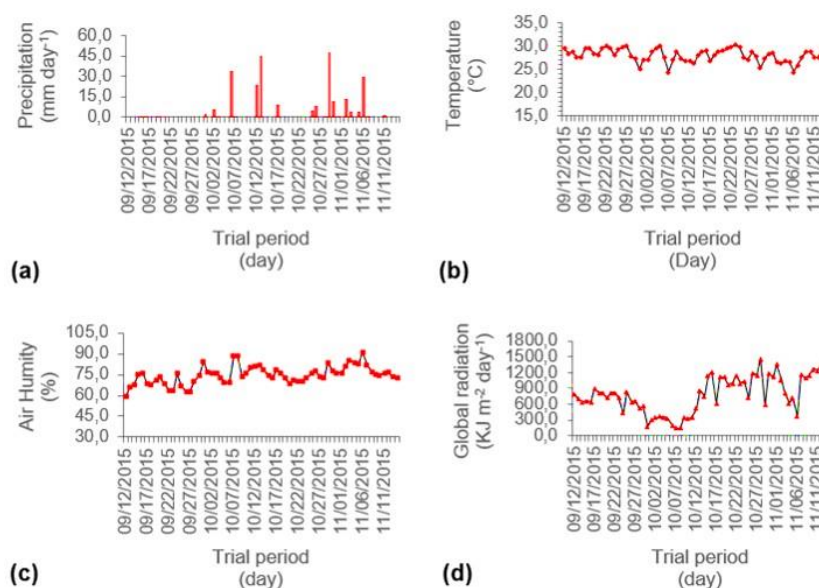
**Table 1***Chemical characteristics and granulometry of partially acidulated phosphate rock¹*

Source	Total phosphorus content				Granulometric fractions 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							
PPR ^A	----- g kg ⁻¹ -----				0.075	0.10	0.25	0.50	1.0	2.0	4.0
					----- 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	SO ₄		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	

Source: Prepared by the authors (2024), 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 de PPR passed in the sieve of 0,075 mm.

Figure 1

Meteorological data: (a) Precipitation (mm day⁻¹), (b) Temperature (°C); (c) Air humidity (%), and, (d) Global radiation (KJ m⁻² day⁻¹), in Humaitá, Amazonas, during the experimental trial.



Source: Prepared by the authors (2024).

After that, the semi-burned stems plus sheath, next to the plots, were collected from topsoil surface with a 0.0415 m² jig together with the semi-burned leaf blades. Then, this material was dried at a forced circulation oven (*Tecnal TE-394/5-MP*, Piracicaba, Brazil) at 67 °C for 72 hours, and weighed at a precision scale (*Tecnal, SHI-BL-3200H*, Piracicaba, Brazil) to determine the surface biomass, prior to the experiment. That biomass was dried at 105



°C for 24 hours and weighted on precision scale for the estimate 0.12 Mg ha^{-1} of biomass C, Mg ha^{-1} , prior to the experiment. That biomass was multiplied by the factor 0.45 and results in 0.054 Mg ha^{-1} of C or 0.20 Mg ha^{-1} of CO_2 (IPCC, 2006).

The homogenization of the *B. brizantha* plant emergence and physiological development was performed on 09/18/2015 in all experimental plots by the desiccation of new emerged tillers by pulverization of 200 L ha^{-1} of gramoxone 200 syrup. As the C and macronutrients cycles are closely associated in pastures (Soussana and Lemaire, 2014), at 09/19/2015, homogeneous dosis of 120.0 kg ha^{-1} of N (as urea) plus 29.1 kg ha^{-1} of K (as KCl), were manual and homogeneously distributed in the soil surface of the plots of Pnb, Pnb+25, Pnb+100 and Pnb+200, after a rain higher than 5.00 mm (Figure 1a). These practices effectively began the experimental trial.

On 10/01/2015, the topsoil layer of the Pb plots areas was sampled with the aid of a dutch auger (*TF10-Sonda Terra, Piracicaba, Brazil*) for the following chemical analysis (SILVA, 2009): pH (water) = 6.60, $\text{Al}^{3+} = 0.0 \text{ cmol}_c \text{ dm}^{-3}$, $\text{H+Al} = 1.80 \text{ cmol}_c \text{ dm}^{-3}$, $\text{Ca}^{2+} = 5.55 \text{ cmol}_c \text{ dm}^{-3}$, $\text{Mg}^{2+} = 4.14 \text{ cmol}_c \text{ dm}^{-3}$, $\text{K}^+ = 0.14 \text{ cmol}_c \text{ dm}^{-3}$, $\text{CEC} = 11.75 \text{ cmol}_c \text{ dm}^{-3}$, $\text{SB} = 9.83 \text{ cmol}_c \text{ dm}^{-3}$, P (Mehlich-1) = 6.0 mg dm^{-3} , V = 84%, m = 0.0%, $\text{SOC} = 8.52 \text{ g kg}^{-1}$, $\text{Cu}^{2+} = 3.13 \text{ mg dm}^{-3}$, $\text{Fe}^{2+} = 1039.95 \text{ mg dm}^{-3}$, $\text{Mn}^{2+} = 77.45 \text{ mg dm}^{-3}$, $\text{Zn}^{2+} = 4.0 \text{ mg dm}^{-3}$. The topsoil boron (B) was 0.10 mg dm^{-3} and sulphate (SO_4^{2-}) was 12.0 mg dm^{-3} according to Raij et al. (2001). The topsoil CSt on the Pb plots area was 5.58 Mg ha^{-1} , prior to the experiment.

3.4 DATA COLLECTION

3.4.1 Biomass Productivity

The data of biomass productivity and soil fertility attributes were collected on a useful sampling area of 3.50 m by 3.0 m (10.50 m^2) delimited within each plot. On 11/14/2015, 56 days after the beginning of the experimental period, the leaf blade (LB) and sheathed stem (ShB) biomass were sampled with a 1.20 m^2 jig. All the plants inside the jig were cut close to the ground with garden shears and packed and identified. Then, the biomass of litter (Bl) was sampled and separated from the soil clods and transferred to a $0.18 \text{ m} \times 0.36 \text{ m}$ newsprint bags. The LB and the ShB were separated by cutting with a manual cutting shears and washed on potable water before washes on HCl solution (0.5%) and distilled water.

On 11/16/2015 each fraction of biomass was repacked on identified $0.18 \text{ m} \times 0.36 \text{ m}$ newsprint bags and dried at a forced air oven (*Tecnal TE-394/5-MP, Piracicaba, Brazil*) at 67



°C for 72 hours. The LB and ShB dry mass productivities and Bl were obtained by weighing on precision scale (*Tecnal, SHI-BL-3200H, Piracicaba, Brazil*) whose values, g jig^{-1} , were converted to t ha^{-1} in Excel worksheet. The partial biomass and partial remaining biomass on the pasture were calculated by the following formulas:

$$\text{PBi} = \text{LB} + \text{ShB} + \text{Bl} \quad (1)$$

$$\text{PreB} = \text{ShB} + \text{Bl} \quad (2)$$

Where:

PBi is the partial biomass on the pasture (kg ha^{-1}), LB is the leaf blade biomass (kg ha^{-1}), ShB is the sheathed stem biomass (kg ha^{-1}), Bl is the biomass of litter (kg ha^{-1}) and PreB is the partial remaining biomass on the pasture (kg ha^{-1}). The PBi and the PreB were named partial because they were not considered the root biomass and the waste biomass of animals returned to the pasture agroecosystem by defecation.

After that, the LB, ShB and Bl were dried a second time on a forced air oven (*Tecnal TE-394/5-MP, Piracicaba, Brazil*) at 105 °C for 24 hours, and weighed on a precision scale (*Tecnal, SHI-BL-3200H, Piracicaba, Brazil*) for the calculation of biomass C in each fraction of biomass by multiplying the dry biomass by the factor 0.45 (IPCC, 2006). The partial biomass C on the pasture (PCBi) was calculated by adding the C contents on the LB, ShB and Bl. The partial remaining biomass C on the pasture (PCreB) was calculated by subtracting the C content on the LB from the PCBi. The avoided C loss as carbon dioxide (CO_2) is the C retained (and not lost) on the pasture biomass produced by the treatments with burning suppression and, or, P fertilization (Pnb, Pnb+25, Pnb+100, Pnb+200) compared to the biomass produced by the P released by the Pb. The avoided C loss (CO_2) was calculated for the PBi and PreB provided by the statistically higher P dosis compared to the Pb, considering that 1.0 Mg of C corresponds to 3.67 Mg of CO_2 (IPCC, 2006).

3.4.2 Topsoil fertility attributes

A representative topsoil sample of the plots (twelve simple samples) was collected with the aid of a dutch auger (*TF10-Sonda Terra, Piracicaba, Brazil*) at 56 days after the beginning of the experimental period and after the biomass collection. The sample was dried at a forced



air oven (*Tecnal TE-394/5-MP, Piracicaba, Brazil*) and packed on identified 0.18 m by 0.36 m newsprint bags. The following soil samples attributes were analysed (Silva, 2009): pH (water), potential acidity (H^+Al), exchangeable aluminum (Al^{3+}) and aluminum saturation (m%), cation exchange capacity (CEC), saturation of basis (V%) and soil organic carbon (SOC), phosphorus (P Mehlich-1), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}), copper (Cu^{2+}), iron (Fe^{2+}), manganese (Mn^{2+}) and zinc (Zn^{2+}). The B and SO_4^{2-} were analyzed according to Raij et al. (2001).

3.4.3 Topsoil carbon stock and partial carbon stocks on the pasture

If there was no significance for SOC (F-test, $p \leq 0.05$), the topsoil partial C stock (Topsoil CSt) will be calculated based in the soil density (Sd) (Embrapa, 1997) and in the mean of SOC (Silva, 2009) provided by Pnb, Pnb+25, Pnb+100 and Pnb+200. In turn, the Topsoil CSt on the pasture burned area (Pb) will be calculated based in the Sd and in the mean of the SOC of its plots. Therefore, the Topsoil CSt (Weldkamp, 1994), the partial C stock on the pasture (PCp) and the partial remaining C stock on the pasture (PCre) were calculated by the following formulas:

$$\text{Topsoil CSt} = (\text{SOC}_{1,2} \times \text{Sd} \times \text{tl}) / 10 \quad (3)$$

$$\text{PCp} = \text{topsoil CSt} + \text{PCBi} \quad (4)$$

$$\text{PCre} = \text{topsoil CSt} + \text{PCreB} \quad (5)$$

Where:

Topsoil CSt is the topsoil partial C stock ($Mg\ ha^{-1}$); Sd is the topsoil apparent density ($kg\ dm^{-3}$); tl is the topsoil thickness (cm); SOC_{1,2} means: SOC₁, which is the mean of SOC provided by Pnb, Pnb+25, Pnb+100 and Pnb+200, and, SOC₂, which is the mean of SOC provided by Pb; PCp is the partial carbon stock on the pasture; PCBi is the carbon stock of the partial biomass on the pasture ($Mg\ ha^{-1}$); PCre is the partial remaining carbon stock on the pasture ($Mg\ ha^{-1}$), and, PCreB is the partial remaining biomass C stock ($Mg\ ha^{-1}$). The PCp and PCre were named partial because they were considered just the topsoil C stock and the biomass C stocks at 56 days of observations.



3.4.4 Nutrient concentration and accumulation

Fifty percent of dry LB were separated to the analysis of N, P, K, Ca, Mg, S (g kg^{-1}) and B, Cu, Fe, Mn e Zn (Silva, 2009) and the calculation of nutrient accumulation (NAc) in the pasture leaf biomass was carried out using the equation that follows:

$$\text{NAc} = \text{LB} \times \text{NC} \quad (6)$$

Where:

NAc is the nutrient accumulation in the LB (kg ha^{-1}); LB is the leaf blade biomass (kg ha^{-1}) and NC is the nutrient concentration in the LB (kg kg^{-1}).

3.5 STATISTICAL ANALYSIS

Experimental data were subjected to the Cochran's homocedasticity test ($p > 0.05$), and the significance of means were verified with the F-test ($p \leq 0.05$) in the MStatC Statistic Software (Michigan State University, USA), in accordance to a randomized blocks-experimental design. Means comparison were carried out with the Tukey's test ($p \leq 0.05$) in the same software. Pearson's linear correlation analysis were performed in Excel worksheet (2013) to study the relationship between the main variables evaluated.

4 RESULTS AND DISCUSSION

4.1 TOPSOIL FERTILITY ATTRIBUTES AND NUTRIENT CONCENTRATION

Variance analyses revealed significant effects of the treatments on the topsoil fertility attributes and nutrient availabilities (Table 2). Higher values of pH (water), SB and V% and lower value of H+Al were observed for Pb, such as those observed by Penn and Camberato (2019). All treatments lead the soil to a medium class of acidity and an adequate availability of basic cations (Alvarez *et al.*, 1999), under the present conditions.

The treatments also increased the P, Mg^{2+} and SO_4^{2-} availabilities but without associations with the acidity attributes or V%. The Pnb+100 and Pnb+200 promoted, respectively, 61.5% and 87.9% more available P than the Pb, inserting the soil to a mean class



of availability (Bernardi *et al.*, 2011). The level of precipitation increased during the experiment (Figure 1a) and provided soil humidity condition to increase the releasing of these nutrients from the PPR.

Table 2

Topsoil fertility attributes and foliar macronutrients concentration of B. brizantha.

Treatment	Topsoil acidity attributes			
	pH (water)	H+Al	SB	V%
		----- cmol _c dm ⁻³ -----		
Pnb	5.50 ab	5.45 a	4.92 b	48.75 b
Pnb+25	5.42 ab	5.82 a	5.06 b	46.75 b
Pnb+100	5.30 b	5.70 a	5.28 b	45.25 b
Pnb+200	5.27 b	5.58 a	5.69 ab	48.00 b
Pb	5.77 a	4.40 b	6.82 a	56.25 a
LSD	0.409	1.033	1.245	7.005
MS _{Residue}	0.033***	0.21***	0.305***	9.65***
CV (%)	3.33	8.50	9.94	6.34
C	0.325	0.372	0.550	0.328
Treatment	Topsoil macronutrient availability			
	P	Mg ²⁺	SO ₄ ²⁻	
	mg dm ⁻³	----- cmol _c dm ⁻³ -----		
Pnb	4.33 c	2.15 ab	7.50 c	
Pnb+25	5.33 c	2.04 b	8.00 b	
Pnb+100	13.65 b	2.17 ab	8.75 b	
Pnb+200	43.66 a	2.37 ab	16.75 a	
Pb	5.25 c	2.74 a	6.75 c	
LSD	3.005	0.077	2.463	
MS _{Residue}	1.776***	0.069**	1.193***	
CV (%)	9.23	11.41	11.94	
C	0.590	0.552	0.407	
Treatment	Macronutrient concentration			
	P	Mg	S	
	----- g kg ⁻¹ -----			
Pnb	1.60 c	4.11 bc	0.62 c	
Pnb+25	1.85 bc	4.47 abc	0.63 c	
Pnb+100	1.93 b	5.13 a	0.932 a	
Pnb+200	2.32 a	4.96 ab	0.83 ab	
Pb	2.14 ab	3.95 c	0.70 bc	
LSD	0.318	0.204	0.236	
MS _{Residue}	0.020***	0.181***	0.011***	
CV (%)	7.17	9.40	13.92	
C	0.548	0.285	0.590	

Source: Prepared by the authors (2024) by the authors (2023), Values within the same column followed by different letters are significantly different at $P < 0.05$ by the Tukey's multiple range test. RMS: residual mean square. 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.

The P concentration showed to be associated to the soil available P ($r = 0.65^{***}$). Either Pnb+100, Pnb+200 or Pb (Table 3) caused larger values than the normal concentration in foliar tissue of *B. brizantha* (Furlani, 2004). Even Pnb provides an adequate P absorption, the burning



becoming unnecessary to the pasture management, as similarly reported by other authors (Farias *et al.* 2016; Rumpel *et al.* 2015; Marahata *et al.* 2014). As a matter of fact, these findings show the simple using of the Pnb or the application of a low or medium dose of soluble P to the soil would be adequate to supply the *B. brizantha* requirements. According to Machado *et al.* (2011) an increase of the dose of soluble P increase its availability and absorption. Porto *et al.* (2012) observed that increasing doses of soluble P leads to 24% higher dry matter production on leaves of *Brachiaria brizantha* cv. Marandu grass at the dosis of 147 kg ha⁻¹ of P₂O₅ in comparison to the absence of phosphorus fertilization.

In turn, mean to high soil fertility classes for Mg²⁺ and SO₄²⁻ availabilities (Rein and Souza, 2004; Alvarez *et al.*, 1999) denote that these nutrients are not a limiting factors for pasture growth (Furlani, 2004). There was sharing of variances between foliar Mg and Mg²⁺ and with P and SO₄²⁻ and between foliar S and P ($0.45^{***} < r < 0.69^{***}$). Despite that fact, the Pnb+100 provided a statistically higher value for Mg concentration that disagrees with Tomasi *et al.* (2012) but indicates a synergistic behavior among these nutrients, as observed by Vichiato *et al.* (2009).

According to the global means in Table 3, micronutrient availabilities did not represent limiting factors to the pasture growth at 56 days of observation. However, the Fe concentration provided by the Pb shows to be 72% higher ($p \leq 0.01$) than the *B. brizantha* requirements. That fact is attributed to the adequate precipitation in November 2015 (Figure 1a) that leads to a high Fe²⁺ releasing and absorption by the plants (Küpper and Andresen, 2016) that presented symptoms of Fe toxicity as described by Zaid *et al.* (2020).

4.2 PRODUCTIVITY, NUTRIENT ACCUMULATION AND BIOMASS CARBON STOCKS

Significant effects of the treatments were also revealed by the variance analyses on *B. brizantha* productivities and P, Mg and S accumulations (Table 4). The PBi observed for Pnb+100 was composed for 34.64% ShB and 59.1% LB. That result represents more food for the cattle, which corroborates to the adoption of this finding on the *B. brizantha* management in the Amazon livestock systems.

**Table 3***Nutrient topsoil availability and foliar concentration of B. brizantha.*

Attribute	Topsoil availability	Class of fertility	Foliar concentration	CPR ¹
N	-	-	12.34 g kg ⁻¹ of N	Below ⁸
K	54.74 mg dm ⁻³ of K ⁺	Mean ²	17.17 g kg ⁻¹ of K	Adapted ⁹
Ca	3.09 cmolc dm ⁻³	Good ³	2.31 g kg ⁻¹ of Ca	Below ¹⁰
B	0.15 mg dm ⁻³ of B	Low ⁴	4,44 mg kg ⁻¹ of B	Low ¹¹
Cu	1.85 mg dm ⁻³ of Cu ²⁺	Mean ⁵	3.64 mg kg ⁻¹ of Cu	Below ¹²
Fe	712.59 mg dm ⁻³ of Fe ²⁺	Good ⁵	53.77 mg kg ⁻¹	Adapted ¹³
Mn	19.57 mg dm ⁻³ of Mn ²⁺	High ⁶	83,93 mg dm ⁻³ of Mn	Adapted ¹⁴
Zn	1.96 mg dm ⁻³ of Zn ²⁺	Mean ⁷	12.49 mg kg ⁻¹ of Zn	Below ¹⁵

Source: Prepared by the authors (2024), ¹Comparatively to the pasture requirements, ²MARTHA JÚNIOR et al., 2007, ^{3,4}ALVAREZ et al., 1999, ^{5,7,8,9,10,12,14}BERNARDI et al. 2011, ^{6,13}WERNER et al., 1996. ¹¹SOUSA & LOBATO, 2004, ¹⁵FURLANI (2004).

However, it is necessary to consider that even the Pnb provided higher amount of biomass for all components of productivity in relation to the Pb. Therefore, the simple pasture burning suppression allied to the phosphate application combined with agronomic dosis of N and K increase the biomass productivity, as also observed by several other authors under similar experimental conditions (Dias *et al.*, 2015; Ieiri *et al.*, 2010; Heringer and Jackes, 2002c). From the economic point of view the Pnb+100 is the recommended treatment since the statistically similar biomass value observed for Pnb+200 was obtained with twice the fertilizer material and the cost is reduced for using.

Moreover, the Pnb+100 also provided statistically higher values for all the biomass productivity components and promoted a significant C retention and, consequently, an avoided C loss from the pasture. The Pbi verified for Pnb+100 captured C equivalent to a decrease of 56.8% on the CO₂ loss compared to the Pb (Table 5).

However, the most important evidence about these findings is shown in Table 4, in which it is possible to observe that more than 2.60 Mg ha⁻¹ of LB provided by the Pnb+100 is no longer available for animal consumption in comparison to the Pb at the 56 days of growth. From the environmental point of view, about 4.29 Mg ha⁻¹ of CO₂ retained in the pasture (and not lost) compared to the Pb is attributed to the C fixed in the LB. That observation shows that the Pb causes a C loss equivalent to the amount of LB that will not be available for animal feed and, consequently, it does not return to the soil in the form of feces and urine, thus accelerating the pasture degradation.

**Table 4***Components of biomass productivity and leaf macronutrient accumulation of B. brizantha.*

Treatment	Components of biomass productivity				
	PB	LB	Bl	ShB	PreB
	----- t ha ⁻² -----				
Pnb	3.99 d	1.85 b	3.33 c	1.80 d	2.13 d
Pnb+25	5.11 c	2.01 b	3.30 d	2.77 a	3.09 a
Pnb+100	6.65 a	3.92 a	4.19 b	2.31 b	2.73 b
Pnb+200	6.31 b	3.82 a	4.24 a	2.06 c	2.48 c
Pb	2.88 e	1.32 c	1.59 e	1.31 e	1.46 e
LSD	0,31	0,285	0,022	0,123	0,142
MS _{Residue}	0.019***	0.016***	0.0001***	0.003***	0.004***
CV (%)	2.73	4.78	4.87	2.88	2.69
C	0.385	0.513	0.324	0.340	0.225

Treatment	Phosphorus and other macronutrient accumulation		
	P	Mg	S
	----- kg ha ⁻¹ -----		
Pnb	3.10 c	8.40 b	1.10 b
Pnb+25	4.10 b	9.00 b	1.30 b
Pnb+100	10.00 a	22.00 a	3.50 a
Pnb+200	10.00 a	20.40 a	3.20 a
Pb	3.10 c	5.50 b	1.00 b
LSD	0.723	3.91	0.39
MS _{Residue}	0.103***	3.008***	0.030***
CV (%)	5.30	13.28	8.59
C	0.413	0.542	0.287

Source: Prepared by the authors (2024). Values within the same column followed by different letters are significantly different at $P \leq 0.05$ by the Tukey's multiple range test. RMS: residual mean square. 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.

Table 5*Avoided loss of carbon dioxide from the pasture of B. brizantha according to phosphorus dosis compared to the pasture burning.*

CPB ¹	Biomass produced	Biomass carbon retention	Biomass CO ₂ Retention	Avoided loss of CO ₂ ²
PB (Pnb+100) ³	6.65	2.99	10.97	6.24
PB (Pb) ⁴	2.88	1.29	4.73	
PB (Pnb+200) ⁵	6.31	2.84	10.43	5.70
PB (Pb) ⁶	2.88	1.29	4.73	
PreB (Pnb+25) ⁶	3.10	1.40	5.14	2.72
PreB (Pb) ⁷	1.46	0.66	2.42	
PreB (Pnb+100) ⁸	2.73	1.23	4.51	2.09
PreB (Pb) ⁹	1.46	0.66	2.42	
PreB (Pnb+200) ⁹	2.49	1.12	4.11	1.69
PreB (Pb)	1.46	0.66	2.42	



Source: Prepared by the authors (2024). ¹components of biomass productivity. ²difference between the CO₂ in the biomass component produced by the statistically higher P dosis and the CO₂ in the biomass produced by the Pb to the topsoil. ³partial biomass in the pasture obtained with Pnb+100 (Mg ha⁻¹). ⁴partial biomass in the pasture obtained with Pb (Mg ha⁻¹). ⁵partial biomass in the pasture obtained with Pnb+200 (Mg ha⁻¹); ⁶partial biomass remaining in the pasture obtained with Pnb+25 (Mg ha⁻¹). ⁷partial biomass remaining in the pasture obtained with Pb. ⁸partial remaining biomass in the pasture obtained with Pnb+100. ⁹partial biomass in the pasture obtained with Pnb+200.

In turn, the LB and the foliar P, Mg and S provided by the Pnb+100 were responsible by significant increasings in the nutrients accumulations (Table 4). In this treatment the pasture accumulates 222.5%, 300% and 250%, respectively for P, Mg and S compared to the Pb. In this sense, this new information requires special attention since it also corroborates to the practical adoption of this dosis of P for *B. brizantha*.

In this same context, there is another important aspect to be considered on the decision about the practical adoption of the Pnb+100. The higher amount of LB provided by the Pnb+100 for animal consumption also reduces the economical costs for production compared to the Pnb+200. From the environmental point of view it is necessary to consider that the LB is not totally transformed into animal product (mainly meat and milk), but, part of it returns to the soil in the form of feces and urine. In turn, the excreted biomass contains a significant part of the C and nutrients ingested by the cattle (Balbinot Júnior et al., 2009), and may contribute to the increasing of the productivity (Braz *et al.*, 2002) and the C retention on pasture biomass.

In time, the Pnb+25 provided by was statistically superior value of PreB (Table 4). That fact may be attributed to the higher amount of ShB provided by that treatment that contributed to the increasing of C retained on the remaining biomass (and decreasing of CO₂ loss) compared to the pasture burning. That observation may be explained by the knowledge widely dissiminated about the growth dynamics of tillers and leaves of forage grasses. At the regrowth in the beginning of the experimental period, the tillers produced enough assimilates for their growth with excess N and P. That fact allowed a fast emergence of new tillers. However, with the increase of precipitation on November 2015, there was high availability of N (applied), but without adequate availability of P applied with the low dose of soluble P in the Pnb+25. Thus, there was imbalance between N and P on this treatment during the experiment, as also presented by Teixeira et al. (2018) in a study with *Brachiaria hybrida* cv. Mulato II. That fact leads to the higher production of tiller biomass to the detriment of leaves. In contrast to that, the Pnb+100 and Pnb+200, the highest doses of P balanced with N, provided higher quantities of LB than the Pnb+25 (Soussana and Lemaire, 2014; Hu et al., 2014).



Unlike the suggestions of Pietramale *et al.* (2020), in 56 days, the pasture vegetates under unbalanced supply of mineral nutrients. Despite this fact, the better productivities observed for Pnb+100 and Pnb+200 may be attributed specifically to the high absorption of P, Mg^{2+} and SO_4^{2-} as well its combined effects on the pasture productivity. Confirming that affirmation, the correlation analysis shows to be proportional to the behavior of PBI ($r = 0.60^{***}$), LB ($r = 0.73^{***}$) and BI ($r = 0.56^{***}$) with the topsoil available P. In this sense, the same behaviour observed among soil P with Mg ($r = 0.50^{***}$) and SO_4^{2-} (0.86^{***}), besides foliar Mg (0.45^{***}) and S (0.44^{***}), become another explanation to the increasing in the biomass produced (Silva and Trevizam, 2015) and, consequently, the retained C (and not lost) on the pasture studied.

Observation like these become the PPR an appropriate material to supply these nutrients from just one source for *B. brizantha*, as also reported by Silva and Trevizam (2015) and Sinclair *et al.* (1996) under different experimental conditions. Heringer and Jackes (2002b) pointed out that the pasture burning is always less productive when compared to any nutrient supply form with soil surface biomass maintenance, whether fertilized or not.

For this reason, it is possible to state that, unlike the burning practice, the inserption of P and other nutrients from the PPR to the soil surface, or, even the simple fire suppression allied to doses of N and K, improve P availability and productivity of biomass that covers the soil and increase the agroecosystem sustainability (Marahata *et al.*, 2014). The present results also confirms that, under a well planned fertilization, the pastures of *B. brizantha* are confirmed as an adequate CO_2 sinks from the atmosphere (Carvalho *et al.*, 2010; Soussana *et al.*, 2010; Maia *et al.*, 2009; Marchão *et al.*, 2009) and, consequently, a potential provider of important environmental services derived from a soil covered by the pasture biomass.

4.3 TOPSOIL CARBON STOCK AND PARTIAL CARBON STOCKS

The treatments did not change the SOC and topsoil CSt ($p \leq 0.05$), probably, due to the short experimental time to an effective C aggregation from the biomass to the topsoil, as also evidenced by Trumbore and Camargo (2009). Therefore, the Pnb+100 provided the higher value of PCp, calculated according to the SOCm1 (Figure 2a).

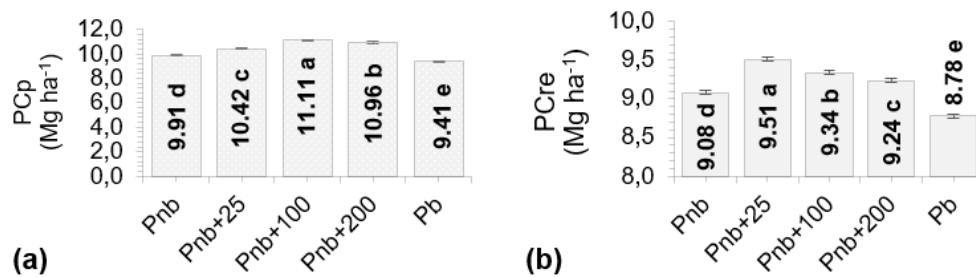
This treatment provided about 15.3% more C retained on the pasture than the Pb, being more than 72.1% of this C occurred in the topsoil layer and about 27.9% on the pasture biomass. Results of other authors agree with these findings for SOC stocks, highlighting that above 70%



of the total C occur in the soil in both natural and cultivated pastures, in association or not with other species (Liu *et al.*, 2016; Moxley *et al.*, 2014a; Amézquita *et al.*, 2010).

Figure 2

Effect of the treatments on: (a) partial carbon stocks, and; (b) partial carbon stock remaining on pasture of *B. brizantha*.



Source: Prepared by the authors (2024). Values followed by the same letters in the vertical column not differ between each other by the Tukey's Test (5% prob.). LSD: (a) = 0.142; (b): 0.071

Differently, the higher value of PCre, quantified for Pnb+25, presented a trend of declining towards to Pb. A short difference of 0.17 Mg ha⁻¹ of PCre was observed between the Pnb+25 and Pnb+100 (Figure 2b) should not remove the focus on the treatment Pnb+100, which proved to be more recommendable for pasture fertilization, since it provided more LB which is grazed by cattle. In turn, the PCre verified for Pnb+100 was 0.56 Mg ha⁻¹ of C higher than the Pb, which represents 2.09 Mg ha⁻¹ of CO₂ really retained on the aboveground biomass, and, comparatively to the Pb, not lost to the atmosphere. About 88.96% of the PCre occurred on the topsoil layer while 11.04% (1.03 Mg ha⁻¹) was retained on the biomass, which constitutes the real increasing on the partial C stock that remains in the pasture of *B. brizantha*.

5 CONCLUSIONS

In these experimental conditions the application of 100 kg ha⁻¹ of phosphorus from partially acidulated phosphate rock and nitrogen and potassium fertilization compared to the burning: i) increase topsoil availability and absorption and accumulation of phosphorus, magnesium and sulfur by the pasture; ii) increase in 3.77 Mg ha⁻¹ (56.69%) of biomass produced and promotes a reduction of 3.78 Mg ha⁻¹ (11.04%) of the loss of carbon dioxide from pasture of *B. brizantha* to the atmosphere. Additionally, even the absence of phosphorus application with nitrogen and potassium fertilization shows to be superior to the burning, becoming this procedure unnecessary to the pasture management. In fact, a simple burning supression or a



low or medium dose of soluble P from partially acidulated phosphate rock and nitrogen and potassium fertilization are adequate to supply *B. brizantha* macronutrient requirements to promote higher biomass productivity and reduce carbon loss compared to burning application.

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