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Liming and phosphorus sources on the yield of BRS Zuri grass

Calagem e fontes de fósforo na produtividade do capim BRS Zuri

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Highlights

Monoammonium phosphate should be applied in fertilizing BRS Zuri grass at planting.
Bayovar natural phosphate should be applied in maintenance fertilization.
Liming increases height and dry matter yield in BRS Zuri grass.
Time after phosphorus and lime application affects the forage nutritional value.

Abstract

Brazilian soils typically exhibit high weathering due to the tropical climate, resulting in acidity, low base saturation, and limited phosphorus levels. Liming and phosphate application are known to enhance soil conditions and forage productivity, but their simultaneous application can reduce phosphorus availability, especially for highly soluble phosphates. Given this, and because adequate levels of phosphorus are essential in initial root development, this study aimed to assess the effects of simultaneous versus spaced application of low-solubility Bayovar reactive natural phosphate and liming, compared to highly soluble monoammonium phosphate, on BRS Zuri grass production. Results revealed that combining phosphates with limestone not only increased plant height and organic matter in the first year but also significantly enhanced fresh and dry matter yields, as well as acid detergent fiber content. Bayovar phosphate exhibited a more pronounced effect in the second year, emphasizing its value as a maintenance fertilizer for BRS Zuri grass. In contrast, monoammonium phosphate demonstrated a stronger influence in the first year, highlighting its role in the initial growth phase. Therefore, utilizing a combination of phosphorus sources with varying availability is recommended to improve soil quality and achieve higher yields in BRS Zuri grass.

Key words: Bayovar natural phosphate. Panicum maximum. Phosphate fertilization. Superphosphate.

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Resumo

Os solos brasileiros, no geral, são muito intemperizados devido ao clima predominantemente tropical, resultando em elevada acidez, baixa saturação de bases e teores de fósforo limitantes. Sabe-se que a calagem e a fosfatagem melhoram as condições químicas do solo e a produtividade de forragem, mas se aplicados juntos no preparo do solo, a disponibilidade do fósforo às plantas tende a reduzir, sobretudo, fosfatos de maior solubilidade. Diante disso, como teores adequados de fósforo são essenciais no desenvolvimento inicial das raízes, objetivou-se avaliar o resultado da aplicação simultânea e espaçada no tempo do fosfato natural reativo de Bayovar de baixa solubilidade com a calagem, comparado ao fosfato monoamônico de maior solubilidade na produção do capim BRS Zuri. Verificou-se que a combinação dos fosfatos com calcário não apenas aumentou a altura das plantas e a matéria orgânica no primeiro ano como, também aumentou significativamente a produtividades de matéria verde e seca e de fibra em detergente ácido. A diferença é que o efeito do Bayovar é mais pronunciado no segundo ano, evidenciando sua importância como adubação de manutenção do capim BRS Zuri, comparado ao fosfato monoamônico que teve maior efeito no primeiro ano, destacando sua influência no arranque inicial. Portanto, recomenda-se a combinação de fontes de fosfatos com disponibilidade diferenciada, visando melhorar a qualidade química do solo para atingir maiores produtividades do capim BRS Zuri.

Palavras-chave: Adubação fosfatada. Fosfato natural de Bayovar. Panicum maximum. Superfosfato.

Introduction

Brazil has the second largest herd globally, with 213.68 million head, representing 13% of the world herd and contributing 8.5% of the country’s GDP (Gross Domestic Product) (Associação Brasileira das Indústrias Exportadoras de Carnes [ABIEC], 2020). The majority of this herd relies on pastures as their primary food source, under extensive grazing systems with limited management control and without nutrient replenishment (Cabral et al., 2021). Consequently, productivity remains low, as indicated by an average animal stocking of only 1.06 AU ha-1, hindering the sector from reaching higher levels (ABIEC, 2020).

This limited productivity is primarily attributed to soil characteristics in the *cerrado* biome, including high acidity, low natural fertility, aluminum saturation, low cation-exchange capacity (CEC), and high phosphorus fixation (A. S. Lopes & Guilherme, 2016). These factors restrict the performance of forage plants. Oxisols, characterized by their clay fraction predominantly composed of Fe and Al oxyhydroxides, exhibit a high phosphate adsorption capacity (Fink et al., 2016). Hence, soil fertility restoration through nutrient replacement is essential for pasture reform, enhancing soil chemical conditions and promoting increased forage and animal meat and milk production.

Among the techniques for restoring soil fertility, liming and fertilization play significant roles. Liming reduces soil aluminum toxicity, increases CEC, promotes organic matter mineralization, and enhances phosphate fertilization efficiency (Morton, 2018). Fertilization, on the other hand, enables the productive maintenance of pastures. However, it is crucial to use fertilizers rationally by applying the necessary nutrients at each stage of forage cultivation. This approach helps prevent wastage and minimize environmental impacts (Cabral et al., 2021).

Phosphorus availability in Brazilian soils is generally low (Teixeira et al., 2018). Phosphorus deficiency results in decreased productivity and carrying capacity for animals (Duarte et al., 2016). Additionally, in the absence of phosphorus fertilization, forage quality is significantly reduced (Duarte et al., 2016). Phosphorus sources are classified based on their solubility (soluble × insoluble), with soluble sources like superphosphates offering immediate phosphorus availability, albeit at a higher cost due to the acidification process (Cabral et al., 2016). However, a portion of soluble phosphorus may form complexes in the soil (Cabral et al., 2016).

Partially soluble sources, such as reactive natural phosphates, can mitigate phosphorus fixation in weathered soils; however, phosphorus release depends on soil acidity, which is neutralized after liming (Cabral et al., 2016). Thus, exploring alternatives that enable the use of Bayovar reactive natural phosphate (NP) in conjunction with liming is crucial for improving soil chemical characteristics.

Among the forage grasses that respond positively to liming and fertilization at planting, those belonging to the genus *Panicum* stand out due to their high forage production per unit area, rapid regrowth, and forage quality. Several breeding programs for *Panicum maximum* have been developed in Brazil, and the most recently released cultivar, BRS Zuri (*Panicum maximum* BRS Zuri), was developed through mass selection from populations collected in Tanzania, East Africa (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2014). BRS Zuri is highlighted for its upright and tall architecture, dark-green long and wide leaves, and resistance to pasture leafhoppers and leaf blight caused by the fungus *Bipolaris maydis*, in addition to exhibiting high productivity, vigor, and carrying capacity and allowing for optimal animal performance (EMBRAPA, 2014). According to studies conducted by EMBRAPA (2014), cv. BRS Zuri demonstrated an annual dry matter yield of 21.8 t/ha, which is 50% higher than that of Tanzania grass. In terms of animal productivity, evaluations conducted in the Amazon region showed yields 11% and 13% higher than those of Tanzania grass during the dry and rainy seasons, respectively, denoting the significant potential of this cultivar (EMBRAPA, 2014).

Although numerous studies have evaluated the efficiency of phosphate sources for fertilizing various forage species in recent years (D. G. Dias et al., 2015; Carneiro et al., 2017; Santiago et al., 2017; Melo et al., 2018; Rodrigues et al., 2020), field research investigating the effects of phosphorus sources associated with limestone on the productive traits of BRS Zuri grass is lacking.

Therefore, studies that enable the rational use of fertilizers, reducing environmental impacts while increasing forage yield, play a vital role in the development of the national agricultural production chain. This study aimed to evaluate the influence of liming and phosphorus sources on the production of BRS Zuri grass.

Material and Methods

This study was conducted at the Agricultural Resocialization Center of Palmeiras in Santo Antônio de Leverger, MT, Brazil (15º51' S and 56º04' W, altitude of 140 m). The region has an Aw type climate according to the Köppen classification, characterized by dry seasons (April to September) and rainy seasons (October to March). The experiment was conducted from July 2019 to April 2021, and climate data for the study period were obtained from the Padre Ricardo Remetter Agrometeorological Station, part of the 9th DISME/INMET network. The average temperature during the experimental period ranged from 24.2 to 32.2 ºC, with a total precipitation of 1,887 mm (Figure 1). The soil underwent chemical and particle characterization (Table 1) and was classified as an Oxisol with a prominent A-horizon and flat relief (Santos et al., 2018).

A randomized block experimental design with four replications was employed. The treatments were arranged in a 3x2 factorial arrangement, with three treatments applied in the presence of liming (Bayovar reactive natural phosphate - NP, monoammonium phosphate - MAP, and no phosphate fertilizer) and three treatments associated with the absence of liming (NP, MAP, and no phosphate fertilizer). For within-year analysis, a 3x2 factorial arrangement was used, considering the combinations of P sources (NP, MAP, and no phosphate fertilizer) and the use of liming (with and without liming). For the analysis of both evaluation years together, a split-plot design was employed, with a 3x2x2 arrangement representing the combinations of P sources (NP, MAP, and no phosphate fertilization), liming (with and without liming), and the evaluated years (1st and 2nd year).

Soil preparation was conducted in August 2019, involving plowing, manual application of dolomitic limestone, and two harrowings to incorporate the limestone and break up the soil in the designated plots. A total of 2.36 t ha^{-1} of dolomitic limestone with a relative neutralizing value of 85% was applied. Base fertilization included manual application of 96 kg ha^{-1} of MAP and 341.50 kg ha^{-1} of NP. Additional corrections for potassium and micronutrient levels in the soil were made using the equivalent of 50 kg ha^{-1} of potassium chloride and 50 kg ha^{-1} of FTE BR 12, respectively, in the plots. Soil correction and all fertilizations followed the crop requirements and the recommendations of Cantarutti et al. (1999).

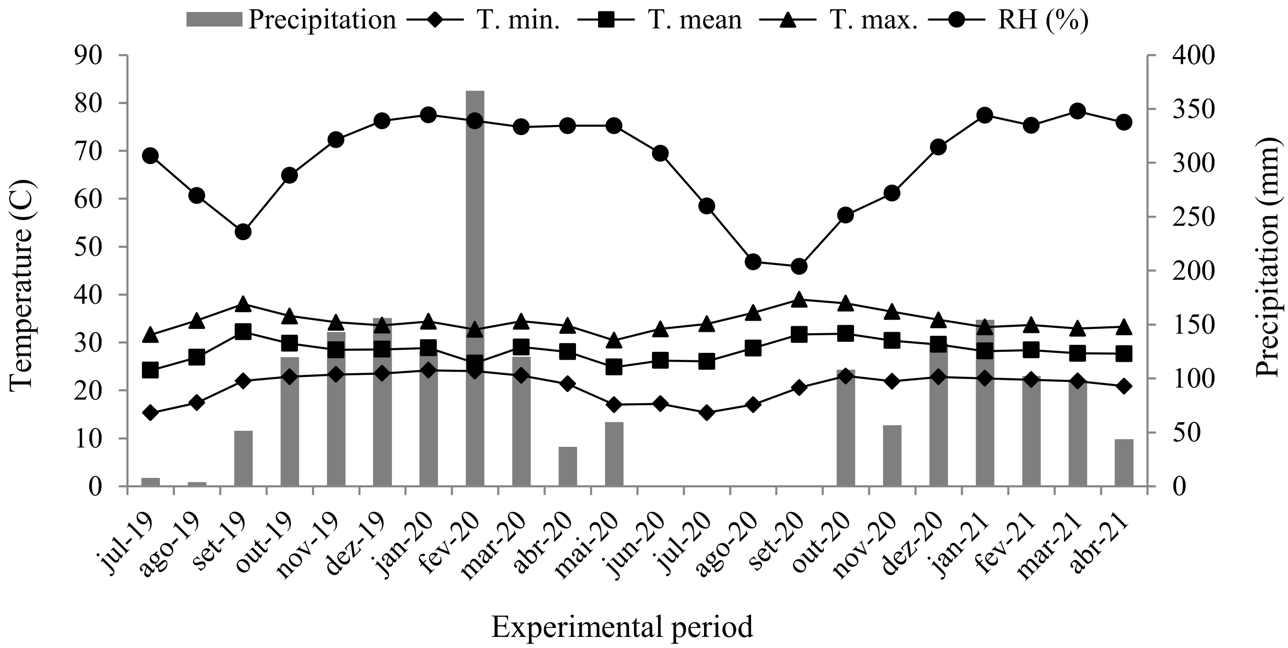

Figure 1. Monthly means of precipitation (mm) and minimum, average, and maximum temperature (ºC) during the experimental period in Santo Antônio of Leverger, MT, Brazil.

Table 1
Plant height, fresh matter yield, and dry matter yield of BRS Zuri grass under different combinations of liming and P sources in the 1st year of evaluation

	PH			FMY		DMY	
Source	W/ liming	W/o liming	Mean	W/ liming	W/o liming	W/ liming	W/o liming
NP	72.50	72.00	72.25 B	53,190.00 Ba	54,697.50 Ba	12,837.68 Ba	12,858.44 Ba
MAP	83.75	77.25	80.50 A	90,333.00 Aa	61,708.50 Ab	21,829.88 Aa	14,526.70 Ab
Control	73.75	62.67	69.00 B	48,154.50 Ca	40,842.00 Cb	11,532.77 Ca	10,003.86 Cb
Mean	76.67 a	71.36 b					

PH: plant height; FMY: fresh matter yield; DMY: dry matter yield. Means followed by the same uppercase letter in the column indicate no difference between phosphorus sources, and lowercase letters in the row indicate no difference between the use and non-use of liming, according to the Scott-Knott test at 5%.

Fertilization was carried out at the time of sowing, by manual broadcast, aiming a better uniformity in the distribution. The phosphorus sources (NP and MAP) were applied 90 days after liming. The forages were sown throughout the entire area, with manual distribution of 12 kg ha^{-1} of seeds, equivalent to 40 points per square meter.

A standardization cut was made when the forage plants reached a height of 75 to 80 cm (95% light interception), measured with a field ruler at a distance of 40 cm from the ground. Topdressing with urea and potassium chloride was applied after each cut in split applications, using 25 kg ha^{-1} of N and 25 kg ha^{-1} of K_2O (Cantarutti et al., 1999). Each plot had dimensions of 5.00 m in length and 4.00 m in width, with the central 12 m^2 area considered usable.

The chemical compositions of the fertilizers used were as follows: dolomitic limestone (20% MgO and 28% CaO with 80% PRNT), NP (29% P2O5; 32% Ca), single superphosphate (20% P2O5; 17% Ca; 11% S), MAP (11% N; 52% P), potassium chloride (58% K), urea (44% N), and FTE BR 12 (9% Zn, 1.8% B, 0.8% Cu, 2.1% Mn, and 0.1% Mo). The natural phosphate had 14% citric acid-soluble phosphorus.

Pasture height was measured using a 1.5 m long metal ruler, graduated in centimeters, from the lower base of the plants to the height corresponding to the average height of the leaves around the ruler. Fresh matter yield (FMY) was determined using a 1.0 x 1.0 m metal frame randomly thrown over each plot, with three replications. The entire green mass of the usable area was harvested, weighed, and FMY was estimated. The samples were then placed in paper bags, labeled, and dried in a forced-air oven at an average temperature of 55 ºC until a constant mass was achieved to determine the air-dried weight. Dry matter yield (DMY) was calculated by multiplying FMY values by their respective dry matter contents.

To determine the chemical composition of the forage, the dried samples were ground in a Wiley mill and analyzed using the near-infrared reflectance spectroscopy (NIRS) method. The ground material was scanned to obtain NIRS spectra using the Zeutec Opto Elektronic Gmbh model EspectraAnalyzer spectrometer with 19 filters. The readings in the NIR device were taken in the reflectance module within the wavelength range of 1100 to 2500 nanometers, resulting in the log1/R (reflectance) spectrum against the wavelength. The estimated variables using NIRS included dry matter (DM), mineral material (MM), organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and indigestible neutral detergent fiber (iNDF) contents.

Results were subjected to analysis of variance at a 5% error probability level, and mean values of the measured variables were compared using the Scott Knott test (α = 0.05). Statistical analyses were performed using Sisvar statistical software (Ferreira, 2019).

Results and Discussion

Table 1 describes the mean plant height (PH) values for the 1st year of evaluation. There was no significant interaction between liming and P sources for the PH variable. However, treatments using limestone had the highest means (76.67 cm) compared to treatments without liming. Among the evaluated P sources, monoammonium phosphate (MAP) had the highest mean, while natural phosphate (NP) and the control (without P) did not differ from each other.

Carneiro et al. (2017) found that phosphate fertilization significantly influenced the height of Mombaça grass at planting, with NP and single superphosphate resulting in 34% and 36% higher heights, respectively, compared to the control treatment. These authors reported heights of 67.43 and 62.96 cm for Mombaça grass fertilized with the same P dose used in this study for NP and single superphosphate, respectively. These values were lower than the mean values found for BRS Zuri grass, which were 72.00 cm and 80.50 cm for NP and MAP, respectively. This difference may be attributed to the longer resting period of BRS Zuri grass (36 days) compared to that of Mombaça grass (21 days).

In the 1st year of evaluation, it appears that there was not enough time for NP to become available to the plants due to its slow solubilization, as it is in a non-assimilable form, resulting in a lower PH compared to treatments using MAP as a P source. The absence or inefficiency of P in the soil solution can hinder plant growth and development, causing a stoppage in tiller emission and leaf growth (Duarte et al., 2016).

Regarding the fresh matter yield (FMY) and dry matter yield (DMY) variables, there was a significant interaction between liming and P source in the 1st year of evaluation. Treatments using MAP had the highest mean FMY values, with 90,333.00 and 61,708.50 kg ha^{-1} with and without liming, respectively, followed by NP. The control treatment had the lowest FMY and DMY values in the 1st year.

In terms of liming, treatments with MAP showed significant differences, with the liming treatment resulting in higher mean values compared to the treatment without liming. For treatments using NP as a P source, no significant differences were found between the liming treatments. The control treatments also differed from each other, with the liming treatments showing higher mean values compared to those without limestone.

For DMY in the 1st year, the highest mean values were observed with MAP fertilization, with 21,829.88 and 14,526.70 kg ha^{-1} for treatments with and without liming, respectively. The NP treatment resulted in intermediate DMY values between MAP and the control, which had the lowest mean values for both liming treatments. Among the liming treatments, those using MAP and the control showed the highest DMY values in the 1st year, while no significant difference was found for the liming treatments with NP.

Carneiro et al. (2017) obtained similar results when working with Mombaça grass, reporting FMY values of 62,112 and 58,506 kg ha^{-1} using NP and single superphosphate, respectively, at P doses equivalent to those used in the present study. These values were lower than those found in the present study, which were 53,190 and 61,708 kg ha^{-1}, respectively, for NP and MAP with liming.

In line with the findings of the present study, Melo et al. (2018) evaluated four sources of phosphorus in the production of Massai grass and observed an increase in DM yield of the forage shoot and roots with phosphorus fertilization. They also found that triple superphosphate, a soluble source of P, had the greatest impact on production at the beginning of forage development.

Carneiro et al. (2017) reported DMY values of 24,804 and 25,244 kg ha^{-1} for NP and single superphosphate, respectively, in Mombaça grass, which were higher than the 12,837 and 21,829 kg ha^{-1} found in this study for NP and MAP. The differences in results may be attributed to variations in dry matter contents, which affect DMY. Costa et al. (2017) conducted a study on Mombaça grass in the Brazilian state of Roraima and reported a DMY of 15,597 kg ha^{-1} for a 36-day rest period using triple superphosphate as a source. In this study, DMY was 14,526.70 kg ha^{-1} at the same P dose.

Similarly, D. G. Dias et al. (2015) found that soluble sources of phosphorus had a positive effect on forage response. They attributed this trend to the intense meristematic activity promoted by phosphorus supply during the initial phase of forage regrowth. They also reported that fertilization with single superphosphate increased DM yield in Piatã grass by 29% compared to the absence of phosphate fertilization.

Cabral et al. (2015) conducted a study to assess the effects of reactive natural phosphate and single superphosphate on Marandu grass. They found that applying higher proportions of reactive natural phosphate than single superphosphate resulted in a reduction in dry matter yield. The authors suggested that increasing the amount of reactive natural phosphate supplied P in a form that is not readily available for plant absorption, thus limiting initial plant development. Conversely, more soluble sources such as single superphosphate and MAP provided a large amount of immediately available P, leading to better pasture development soon after application to the soil (Carneiro et al., 2017).

The results from the first year of evaluation regarding PH, FMY, and DMY indicated that soluble phosphorus sources like MAP facilitated greater short-term P absorption, promoting faster plant response, greater initial development, and higher yield gains in a short period compared to less soluble P sources, as is the case of NP. Cabral et al. (2015) emphasized the importance of partially meeting the plant's P needs with a readily available source of phosphorus. Additionally, MAP contains nitrogen, which is beneficial for the short-term development of forage grasses, as it is the most essential nutrient for regrowth (Cantarutti et al., 1999). Natural phosphate, on the other hand, lacks nitrogen in its composition.

In the second year of evaluation, there was no significant interaction between liming and P sources for PH FMY, or DMY. However, the treatments that incorporated liming showed the highest mean values (Table 2). Among the P sources studied, NP exhibited the highest mean values for PH, FMY, and DMY in the second year.

Table 2
Plant height, fresh matter yield, and dry matter yield of BRS Zuri grass under different combinations of liming and P sources in the 2nd year of evaluation

	PH			FMY			DMY		
Source	W/ liming	W/o liming	Mean	W/ liming	W/o liming	Mean	W/ liming	W/o liming	Mean
NP	77.50	73.00	75.25 A	69,840.00	67,995.00	68,917.50 A	23,112.67	21,898.93	22,505.80 A
MAP	69.75	63.50	66.63 B	59,497.50	47,520.00	53,508.75 B	19,631.92	15,103.96	17,367.94 B
Control	68.00	53.67	61.86 B	56,610.00	41,170.00	49,992.86 B	18,107.58	13,486.12	16,126.95 B
Mean	71.75 a	64.27 b		61,982.50 a	53,233.64 b		20,284.06 a	17,133.63 b	

PH: plant height; FMY: fresh matter yield; DMY: dry matter yield. Means followed by the same uppercase letter in the column indicate no difference between phosphorus sources, and lowercase letters in the row indicate no difference between the use and non-use of liming, according to the Scott-Knott test at 5%.

Santiago et al. (2017) observed a 28% increase in forage dry matter yield of Marandu grass with the use of liming in the first cut. In the second and third harvests, they found that liming provided a 39% and 31% better utilization of phosphorus, respectively. According to Morton (2018), the combined use of P and liming has a beneficial interaction, with liming reducing P fixation and preventing precipitation with aluminum and cationic micronutrients (Fe, Mn, Zn, and Cu). The increased cation exchange capacity (CEC) makes toxic aluminum unavailable, thereby improving phosphate fertilization efficiency.

Santiago et al. (2017) also noted that liming reduces aluminum and manganese toxicity while increasing calcium and magnesium levels. This delay in the plant's senescence process leads to increased leaf lifespan, as leaves are the most nutritious plant fractions for animal diets. These results can be attributed to the increased P supply by plants, promoting greater root development and allowing for the exploration of a larger volume of soil, resulting in enhanced nutrient absorption and increased plant height.

In comparison to the present study's findings for P sources, D. G. Dias et al. (2015) evaluated the production of Piatã grass using different combinations of soluble phosphorus and natural phosphate. They found that regardless of the combination of single superphosphate and natural phosphate, the mean values did not differ significantly, and all treatments had higher mean values than the control. Cabral et al. (2021) observed that in the absence of P, grasses of the genus *Panicum* implanted in an Oxisol with low P content experienced a reduction in production of approximately 98.5%, highlighting the impact of this nutrient on pasture formation for this genus.

Similar to the present study, Melo et al. (2018) evaluated the residual effects of four P sources (triple superphosphate, Djebel-Onk reactive natural phosphate-based fertilizers ("FH Pastagem"), waste phosphate rock, and NP) on the yield of *Panicum maximum* Massai. They observed that from the second cut onwards, the less soluble sources such as NP and Djebel-Onk reactive natural phosphate-based fertilizers showed better performance. The authors attributed this trend to the gradual release of phosphate ions into the soil solution over time, making them available to plants.

The higher values observed in treatments using reactive natural phosphate can be explained by the slow-release nature of low-solubility fertilizers, which gradually release phosphorus over the long term (Duarte et al., 2016). As the evaluations were conducted for two consecutive years, the gradual release was crucial for maintaining consistent forage production throughout this period. Duarte et al. (2016) emphasized that slow-release fertilizers gradually make phosphorus available to plants, which is essential for improving the grazing cattle’s diet, increasing forage productivity, and enhancing nutritional quality.

According to R. M. Souza et al. (2014), more soluble sources provide large amounts of P immediately after application, leading to better initial pasture development. However, in the long term, these fertilizers tend to have diminishing effects on forage production since most of the available P has already been released, resulting in reduced productivity of forage dry mass. Moreover, when applied to weathered soils, highly soluble phosphate fertilizers lose a significant portion of the available P through adsorption, due to rapid solubilization, and have a greater interaction with clay minerals in weathered soils, reducing P absorption efficiency and grass production (D. G. Dias et al., 2015).

The results demonstrate that slow-release phosphate fertilizers do not promote substantial short-term yield gains but maintain productivity in perennial forages for longer periods. Therefore, fertilizers like NP, which gradually release P in the soil, are desirable for the cultivation of perennial forage grasses that occupy the same area for extended periods and require P throughout their growth cycle.

In the first year of evaluation, a significant interaction effect between liming and P sources was observed for the acid detergent fiber (ADF) content. In treatments with liming, the highest mean values were obtained with NP and the control (Table 3). In treatments without liming, NP and MAP showed the highest mean values for ADF. There was no difference in ADF between treatments with NP and MAP, with or without liming, in the first year. The control treatments with liming had the highest mean ADF values compared to those without liming.

For the organic matter (OM) content, there was an effect of P sources in the first year, with the highest means observed in the control treatment. This can be explained by the absence of P in this treatment, resulting in a higher OM content due to the reduced mineral material (MM) content. The chemical composition of forage can be influenced by soil fertility, and a lower supply of minerals through the soil leads to higher OM content in plants. The mean values for MM, dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and indigestible neutral detergent fiber (iNDF) in the first year of evaluation were 8.34, 23.95, 10.05, 66.18, and 23.09%, respectively.

Table 3
Chemical composition of BRS Zuri grass under different combinations of liming and P sources in the 1st year of evaluation

	ADF		OM		
Source	W/ liming	W/o liming	W/ liming	W/o liming	Mean
NP	31.66 Aa	32.35 Aa	91.52	91.64	91.58 B
MAP	31.51 Ba	32.72 Aa	91.58	91.64	91.61 B
Control	31.23 Aa	30.15 Bb	91.92	91.98	91.95 A
Mean			91.67	91.75	

ADF: acid detergent fiber; OM: organic matter. Means followed by the same uppercase letter in the column indicate no difference between phosphorus sources, and lowercase letters in the row indicate no difference between the use and non-use of liming, according to the Scott-Knott test at 5%.

In the second year of evaluation, the chemical composition of BRS Zuri grass did not show a significant difference for the interaction between liming and P sources. This unexpected result indicates that fertilization and liming did not affect the nutritional value of BRS Zuri grass. The mean values for MM, DM, CP, NDF, ADF, iNDF, and OM in the second year of evaluation were 10,32; 32,44; 3,22; 64,80, 29,64; 22,57 e 89,60, respectively.

In a similar study, Silva et al. (2020) evaluated the chemical composition of BRS Zuri grass under different water depths and salinity levels and found no interaction between these factors and ADF levels. F. J. Dias et al. (2007) also investigated the chemical composition of Mombaça grass fertilized with different P sources and found no significant changes in the chemical composition of the grass. D. J. A. T. Souza et al. (2020) examined the morphological, productive, and nutritional characteristics of Mombaça grass with different soluble and natural P sources and found that treatments using rock waste and the control (without phosphate fertilization) resulted in higher CP contents, with no significant difference between them, indicating that P application did not affect the CP content of Mombaça grass.

However, D. J. A. T. Souza et al. (2020) stated that higher P content in forage composition leads to lower costs for supplementing cattle, as part of their mineral needs can be met through roughage. In the present study, although there were slight differences in the chemical composition of the grass, these alterations in ADF and OM contents are not nutritionally significant, indicating that liming and the evaluated P sources did not compromise the quality of BRS Zuri grass in the first year of evaluation.

Regarding the PH variable, treatments with combinations of liming and/or P sources showed higher values than the control treatment in the first year of evaluation (Table 4). In the second year, the lowest mean PH values were observed in the control treatment, followed by the MAP treatment, which showed intermediate mean values. The other treatments had the highest PH values and did not differ significantly from each other.

The Liming + MAP and MAP treatments showed a significant difference in PH between the first and second years of evaluation, with lower mean values in the second year. However, for the other treatments, there was no significant difference in PH between the two years. Carneiro et al. (2017) found that the application of phosphate fertilizers resulted in higher PH values for Mombaça grass, with NP and single superphosphate providing PH values of 72.00 and 75.00 cm, respectively, which are lower than those found in this study for NP and MAP in the first year (72.00 and 77.25 cm) and greater than those found in the second year (73.00 and 63.50 cm).

Table 4
Plant height, fresh matter yield, and dry matter yield of BRS Zuri grass under different combinations of liming and P sources in the 1st and 2nd years of evaluation

Source	Year	Liming + MAP	Liming + NP	Liming	MAP	NP	Control
PH	1st	83.75 Aa	72.50 Aa	73.75 Aa	77.25 Aa	72.00 Aa	62.67 Ba
	2nd	69.75 Ab	77.50 Aa	68.00 Aa	63.50 Bb	73.00 Aa	53.67 Ca
FMY	1st	90,333.00 Aa	53,190.00 Cb	48,154.50 Db	61,708.50 Ba	54,697.50 Cb	40,842.00 Da
	2nd	59,497.50 Bb	69,840.00 Aa	56,610.00 Ba	47,520.00 Cb	67,995.00 Aa	41,170.00 Ca
DMY	1st	21,829.88 Aa	12,837.68 Bb	11,532.77 Bb	14,526.70 Ba	12,858.44 Bb	10,003.86 Bb
	2nd	19,631.92 Ba	23,112.67 Aa	18,107.58 Ba	15,103.96 Ca	21,898.93 Aa	13,486.12 Ca

PH: plant height; FMY: fresh matter yield; DMY: dry matter yield. Means followed by the same uppercase letter in the column indicate no difference between the combinations of liming and P sources, and lowercase letters in the row indicate no difference between years, using the Scott-Knott test at 5%.

In the first year, the highest mean values for FMY were observed in the Liming + MAP treatment, followed by the MAP treatment, which had higher values than the Liming + NP and NP treatments. The lowest mean FMY values in the first year were found in the Liming and control treatments. In the second year, the highest mean values for FMY were found in the Liming + NP and NP treatments.

When comparing the first and second years, only the control treatment did not show a significant difference in FMY. The Liming + MAP and MAP treatments had the highest mean values in the first year, whereas the Liming + NP, Liming, and NP treatments had the highest mean values in the second year.

For the DMY variable, the highest mean values in the first year were found in the Liming + MAP treatment, with no significant difference between the other treatments. In the second year, the highest values were found in the Liming + NP and NP treatments, while the MAP and control treatments had the lowest mean values.

There was a significant difference in DMY between the first and second years for the Liming + NP, Liming, NP, and control treatments. In the second year, these treatments had higher mean values compared to the first year. The other treatments did not show significant differences.

These results indicate that in the first year of evaluation, the use of MAP favored the growth of the forage plants, as the treatments with this soluble source of P had the highest PH values compared to the other treatments. Due to its solubility, MAP likely released a higher initial amount of P to the plants, leading to faster growth compared to NP. Furthermore, MAP contains 11% nitrogen in its composition, which promotes cell division and tissue growth, resulting in stem elongation and larger leaf blades, supporting initial plant growth (M. N. Lopes et al., 2013).

In contrast, the treatments with NP exhibited higher mean values during the second year of evaluation, indicating that the gradual release of phosphorus facilitated the sustained performance of the forage plants over extended periods. D. G. Dias et al. (2015) found that the gradual release of P from natural phosphate enhances the performance of forage plants, as they are able to absorb it throughout their entire growth cycle. Phosphorus sources with lower solubility have a greater residual effect on the soil, primarily contributing to long-term fertility maintenance, although they are less effective than soluble phosphates in the short term (Duarte et al., 2016).

While the treatments with MAP provided higher FMY and DMY in the second year of evaluation compared to the control, the achieved mean values were lower than expected, likely due to the rapid solubility of P followed by its fixation in the soil. Consequently, it can be inferred that over the medium and long term, in the absence of P replenishment, fertilization with MAP may diminish the yield of BRS Zuri grass in comparison to fertilization with NP, which maintained the yield until the second year of evaluation.

The highest values observed in the control treatment for FMY and DMY variables during the second year of evaluation can likely be attributed to variations in climatic conditions, as these treatments did not receive any fertilization throughout the experimental period. Consequently, in the absence of phosphorus fertilization, the plants solely rely on the P present in the soil solution for their maintenance, which restricts their development (Duarte et al., 2016). In such cases, the variation in forage performance likely occurs due to factors such as precipitation, temperature, and photoperiod (Carmo et al., 2018).

Regarding DM and MM, lower mean values were observed in the first year of assessment compared to the second year. Conversely, for CP, NDF, ADF, iNDF, and OM, the highest mean values were found in the first year of evaluation (Table 5). Duarte et al. (2016) evaluated Piatã grass fertilized with P sources with different solubilities and found no significant difference in the chemical composition of Piatã grass.

Table 5
Chemical composition of BRS Zuri grass under different combinations of liming and P sources in the 1st and 2nd years of evaluation

Variable	Year	Liming + MAP	Liming + NP	Liming	MAP	NP	Control	Mean
DM	1st	24.18	24.13	23.96	23.54	23.50	24.50	23.97 B
	2nd	32.99	33.10	31.95	31.68	32.18	32.85	32.44 A
MM	1st	8.51	8.41	8.14	8.43	8.43	8.07	8.34 B
	2nd	10.15	10.53	10.44	10.14	10.32	10.31	10.32 A
CP	1st	10.92	9.80	9.89	10.18	9.86	9.54	10.05 A
	2nd	2.95	3.57	3.43	2.77	3.47	3.10	3.22 B
NDF	1st	65.14	66.26	66.16	65.70	66.78	67.33	66.18 A
	2nd	65.20	64.07	64.19	65.53	64.81	65.05	64.80 B
ADF	1st	31.51	31.65	31.23	32.72	32.35	30.15	31.67 A
	2nd	29.39	29.79	30.34	29.61	29.21	29.41	29.64 B
iNDF	1st	23.62	22.79	23.08	23.03	23.20	22.74	23.09 A
	2nd	22.54	23.01	22.71	22.18	22.55	22.39	22.57 B
OM	1st	91.58	91.52	91.92	91.64	91.64	91.98	91.70 A
	2nd	88.94	89.58	89.66	89.92	89.76	89.76	89.60 B

DM: dry matter; MM: mineral matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; iNDF: indigestible neutral detergent fiber; OM: organic matter. Means followed by the same uppercase letter in the column indicate no difference between the combinations of liming and P sources, and lowercase letters in the row indicate no difference between years, using the Scott-Knott test at 5%.

The elevated CP levels observed in the first year of evaluation indicate greater absorption of P immediately after application. The reduction in CP content during the second year of evaluation is likely due to the presence of senescent material in the canopy. According to Van Soest (1994), the smaller the presence of senescent material in the morphological composition of forage, the higher the nutritional value, as these components have low CP levels, resulting in reduced digestibility of the forage.

Similarly, it was expected that MM contents would also exhibit the highest mean values in the first year of evaluation, as phosphate fertilizers make a large amount of P readily available after planting, benefiting the plants in the short term by facilitating greater nutrient absorption and consequently increasing their nutritional value. Insufficient levels of MM can adversely affect animal performance since mineral deficiency in forage limits animal development and increases the incidence of health problems (Van Soest, 1994).

Furthermore, a decrease in the nutritional value of BRS Zuri grass was anticipated during the second year of evaluation, considering that regardless of the P source used, the longer P remains in the soil, the more prone it is to fixation, resulting in reduced availability for plant absorption and negatively affecting the nutritional value of the forage, which fails to meet its nutritional requirements. As stated by Santos et al. (2011), phosphorus exhibits strong interaction with the clay fraction of the soil, leading to a significant reduction in its concentration in the soil solution within 24 h of application in Oxisol.

The obtained results underscore the importance of phosphate fertilization in enhancing soil fertility and restoring the productivity of BRS Zuri grass. Both sources of phosphate offer benefits to the plants, but they should be utilized at different times to optimize their efficiency. Additionally, the combined application of lime and P sources exhibited a beneficial interaction, resulting in improved yields of BRS Zuri grass. The results obtained with Bayovar natural phosphate highlight its significant potential as a phosphorus source for perennial forage grasses like BRS Zuri grass.

Conclusions

In the first year of evaluation, monoammonium phosphate, with or without liming, resulted in the highest plant heights and yields, making it the recommended choice for the time-of-planting fertilization of BRS Zuri grass.

During the second year of evaluation, Bayovar reactive natural phosphate, with or without liming, provided the highest yield, establishing it as the recommended option for maintenance fertilization of BRS Zuri grass.

The incorporation of liming led to increased plant height in both evaluation periods, as well as higher fresh and dry matter yields specifically in the second year.

The timing of phosphorus and limestone application in the soil affected the chemical composition of BRS Zuri grass.

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