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Nutritional content of pastures with phosphate fertilization in 2 calcareous soils

Conteúdo nutricional de pastagem com adubacao fosftada em solos calcários

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ABSTRACT - Alkaline soils present large amounts of calcium carbonates, with precipitation of insoluble calcium phosphate. The objective of the research was to determine the effects of the P application on the nutrient levels of the foliar tissue of *Pennisetum* pastures in calcareous soils in Córdoba-Colombia. Soil samples were collected from two locations in the Department of Córdoba. A completely randomized design with a 2 x 3 x 6 factorial arrangement (Vista Hermosa and Carolina), there *Pennisetum* species (king grass, Cuba OM-22, and *Pennisetum purpureum*), and six P doses (0, 80, 150, 250, 400, and 650 kg ha^{-1}), applied as P_2O_5, was used. The addition of P did not increase the contents of N, K, Ca, and Mg in the king grass, *Pennisetum purpureum*, and Cuba OM-22 pastures. However, in the calcareous soils of Carolina, king grass, *Pennisetum purpureum,* and Cuba, OM-22 absorbed higher amounts of P.

Keywords: Alkaline soils. Foliar analysis. Insoluble compounds. Phosphorus precipitation. Grasses. Nutrition mineral.

RESUMO - Solos alcalinos podem apresentar grandes quantidades de carbonatos de cálcio, houve precipitação de fosfato de cálcio insolúvel. O objetivo da pesquisa foi determinar a resposta da aplicação de fósforo no conteúdo nutricional do tecido foliar das pastagens *Pennisetum purpureum* e dois híbridos com espécies do gênero *Pennisetum* em solos calcários do Departamento de Córdoba-Colômbia. Este estudo foi realizado em estufas e laboratórios da Faculdade de Ciências Agrárias da Universidade de Córdoba, localizada no município de Montería. O solo calcário foi coletado em dois locais do Departamento de Córdoba fazenda Vista Hermosa, e o segundo local correspondeu à localidade de Carolina, e Planeta Rica. Utilizou-se o delineamento inteiramente casualizado com arranjo fatorial 2x3x6 com quatro repetições: dois tipos de solo (Vista Hermosa e Carolina); três gramíneas King Grass (Híbrido entre *Pennisetum purpureum* y *Pennisetum typhoides*), Cuba OM-22 (Hibrido entre *Pennisetum purpureum* Cuba CT-169 y *Pennisetum glaucum* Tiffton) e elefante roxo (*Pennisetum purpureum*); seis doses de fosfato (0, 80, 150, 250, 400 e 650 kg ha^{-1}) aplicado na forma de P_2O_5. A aplicação de P no solo não aumentou os teores de N, K, Ca e Mg na pastagem King Grass, *Pennisetum purpureum* e Cuba OM-22 estabelecidos nos solos calcários de Vista Hermosa e Carolina. Nos solos calcários da Carolina, King Grass, *Pennisetum purpureum* e Cuba, OM-22 absorveram maiores quantidades de fósforo.

Palavras-chave: Solos alcalinos. Análise foliar. Compostos insolúveis. Precipitação de fósforo. Gramíneas. Nutrição mineral.

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INTRODUCTION

Calcareous soils are widespread in arid and semi-arid regions and comprise over one-third of the world's land surface area. They are characterized by high alkalinity (pH from 7.3 to 8.5) and a low availability of microelements; some horizons can contain from 1% to 95% of $CaCO_3$ (TAALAB et al., 2019). This potentially affects the availability of macronutrients, which may delay germination or reduce plant growth and productivity (BHARGAVARAMI; GULDEKAR; BALAKRISHNAN, 2013).

Calcareous soils contain high amounts of phosphorus in insoluble forms (calcium phosphate, $Ca_3(PO_4)_2$), which limits its availability for plants (LOPES; SOUZA, 2015). When P fertilizer is provided to calcareous soils, some fixation reactions occur, which gradually decrease its solubility and, eventually, plant availability (TAALAB et al., 2019).

The suitability of calcareous soils for agriculture depends on management strategies, such as the addition of organic materials, to improve the availability of nutrients, particularly phosphorus (KARIMI; BAHMANYAR; SHAHABI, 2012). This situation is similar to the conditions for pasture and forage crops that are cultivated in the calcareous soils of the department of Córdoba, one of the main producers of cattle in the country, with a share of 5.44% in meat and 5.10% in cattle; such pastures are mainly used in the dry season (DANE, 2016). On the other hand, Miranda, Ayala and Diez (2016) found that Cuba OM-22 grass (*Pennisetum purpureum* x *Pennisetum glaucum*) requires high amounts of fertilizers. Xu et al. (2016) concluded that high N and P levels (90 and 120 kg ha^{-1}) result in optimum plant height, green forage, and dry mass. However, in forage, biomass production and nutrient concentration are determined by the availability of soil nutrients (DIOS, 2018; CERDAS, 2015).

According to Moreira et al. (2006), P fertilization increases the annual forage production by 45 kg of dry mass per kg of applied P and by 90 kg of dry mass per kg of P applied together with N fertilization. Locher (2016) explain that P also plays an important role in the cell structure, being a component of phospholipid membranes and RNA and DNA nucleotide ribbons, as well as energy supply via adenosine triphosphate (ATP). In this study, we aimed to determine the effects of P application on the nutritional content of the foliar blade tissue in different pastures on calcareous soils in Córdoba-Colombia.

MATERIALS AND METHODS

Location

This research was carried out in greenhouses and laboratories of the Faculty of Agricultural Sciences of the University of Córdoba, Montería, Córdoba, Colombia, at 8 ° 48 N and 75 ° 52' W, 15 m above sea levels. Average annual precipitation is 1346.1 mm, with a relative humidity of 84%, an average annual temperature of 27.4°C, and 2.108,2 h of sunshine per year (PALENCIA; MERCADO; COMBATT, 2006).

Soil sample collection

Calcareous soils were collected from two sites, sampling 800 kg of soil at a depth of 0–20 cm. One site was located at the Vista Hermosa farm, Montería (08 ° 48'27.5 " N and 75 ° 56'26.1 " W), and one in the township of Carolina, Planeta Rica (08º 49 ’27.4’ N and 75º 62 ’61, 0’’ W). The soil samples were transferred to the Soil and Water Laboratory of the University of Córdoba, where 1 kg was used for chemical analysis (Table 1); the rest was subjected to drying, grinding, and sieving through a 4-mm sieve.

Table 1. Chemical characterization of calcareous soil samples from Monteria and Planeta Rica.

Soils	pH	M.O	S	P	Ca	Mg	K	Na	CIC	Cu	Fe	Zn	Mn	Texture
	1:1	%	--mg kg^{-1}--		-----------------cmol$_c$ kg^{-1}--------------					--------mg kg^{-1}--------				
Vista hermosa-Montería	7.7	2.1	17.6	19.7	30.6	5.6	1.1	0.2	37.6	0.3	0.4	0.3	6.4	clayey soil
Carolina-Planeta Rica	7.3	1.8	24.8	18.5	62.4	10.4	0.6	0.3	73.8	0.1	3.4	0.1	1.0	clayey soil

pH: soil-water ratio 1:1; M.O: Walkley-Black; S: monobasic calcium phosphate 0.008 mol L^{-1}; P: Bray-II modified; Ca^{2+}-Mg^{2+}-K^{+}-Na^{+}: Ammonium acetate 1.0 mol L^{-1} pH 7.0; KCl 1.0 mol L^{-1}; CIC: Sum of bases; Cu-Fe-Zn Mn: Mehlich-1; Texture.

Experimental design

A completely randomized 2 x 3 x 6 factorial design was used, with two soil types (Vista Hermosa and Carolina), three *Pennisetum grasses* (king grass (hybrid between *Pennisetum purpureum* and *Pennisetum typhoides*), Cuba OM -22 (hybrid between *Pennisetum purpureum* Cuba CT-169 and *Pennisetum glaucum Tiffton*), and purple elephant (*Pennisetum purpureum*)), and six concentrations of P_2O_5 (0, 80, 150, 250, 400, and 650 kg ha^{-1}).

The experimental units consisted of transparent plastic bags with 8 kg of soil, to which the different (P) concentrations were applied 15 days before sowing. Subsequently, sowing was carried out with three cuttings per bag, and 15 days later, only 1 cutting remained. Fertilization was carried out with an equivalent of 300 kg ha^{-1} ammonium sulfate and 150 kg ha^{-1} K_2O.

At 90 days after the crop was established, leaf blade samples were collected to determine the levels of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). For this, 500 g of leaf tissue from each treatment was taken, dried in a forced circulation oven at a temperature of 70°C for 72 h, and ground in an IKA MSF-1 micromill. The levels of Ca, Mg, and K were determined by wet digestion of the plant samples (HNO_3: $HClO_4$ in relation to 3:1 v/v) at a temperature of 350°C, and K, Ca, and Mg were quantified by atomic spectroscopy in a Perkin Elmer spectrometer 3110. Nitrogen was quantified by the Kjeldahl method and phosphorus by the colorimetric method with ammonium molybdate (IGAC, 2006).

Data were subjected to analysis of variance, Tukey's comparison of the means test, and regression analysis ($p < 0.05$). In addition, Pearson´s correlation of P with N, K, Ca, and Mg of the pastures in each soil was carried out to determine the influence of P on the absorption and/or accumulation of the other elements. The data were processed with the statistical program SAS (Statistical Analysis Software) version 9.4.

RESULTS AND DISCUSSION

Table 2 shows the foliar levels of N, P, K, Ca, and Mg and the independent effects and interactions of calcareous soils, grasses, and phosphorus doses.

Table 2. F and p values of the analysis of variance of the foliar contents of N, P, K, Ca, and Mg of two calcareous soils, three grass types, and five P doses.

Fuente	GL	N		P		K		Ca		Mg	
		F	*p*-valor	*F*	*p*-valor	*F*	*p*-valor	*F*	*p*-valor	*F*	*p*-valor
Soil (S)	1	62	<0.01***	76.5	<0.01***	0.52	0.47	54.6	<0.01***	4.43	0.04*
Grass (G)	2	15	<0.01***	33.5	<0.01***	419.75	<0.01***	13.27	<0.01***	0.37	0.69
Phosphorus dose (D)	5	25	<0.01***	37.5	<0.01***	52.96	<0.01***	35.84	<0.01***	2.00	0.08°
Interaction S-G	2	2	0.14	7.0	<0.01***	401.29	<0.01***	17.58	<0.01***	5.00	<0.01***
Interaction S-D	5	2	0.08°	5.5	<0.01***	2.05	0.08°	1.31	0.26	3.90	<0.01***
Interaction G-D	10	6	<0.01***	1.0	0.45	5.77	<0.01***	1.94	0.05*	2.77	<0.01***
Interaction S-G-D	10	1	0.45	1.5	0.15	2.91	<0.01***	2.07	0.03*	2.30	0.02*
Residuals	108										
CV(%)		8.45		26.49		13.85		20.64		14.91	

GF: degree of freedom; F value; differences at 10%; *: differences at 5%; ***: differences at 0.1%.

Nitrogen

Foliar nitrogen was influenced by the interaction between phosphorus doses and calcareous soils (p-value = 0.08) and pastures (p-value = < 0.01) (Table 2). When analyzing the foliar N content of the pastures, regarding the interaction between P doses and calcareous soils, we found that the foliar N decreased linearly with the application of phosphorus. In addition, the soil of Vista Hermosa (Monteria, Colombia) presented higher foliar N contents (Figure 1a), which can be explained by the good nutritional balance and the high content of organic matter (2.15%) at this site (Table 1). In addition, the Vista Hermosa soil presented a lower Ca content, which reduces the risk of the formation of insoluble compounds such as calcium phosphate, and a greater amount of plant-available P. This highlights the importance of N, which is the main element for protein synthesis, enzymes involved in photosynthesis, making N a key factor in crop growth and productivity (BEIER et al., 2018).

Regarding the interaction between grasses and phosphorus doses, we found that the foliar N level of the grasses decreased linearly as the P dose increased, and *P. purpureun* (elephant grass) presented the best response when increasing the P dose (Figure 1b). A possible explanation for this dilution response is that when applying the P in the pre-sowing phase, the levels of P are in balance with those of N, Ca, Mg, and K, resulting in a better absorption of N and other elements.

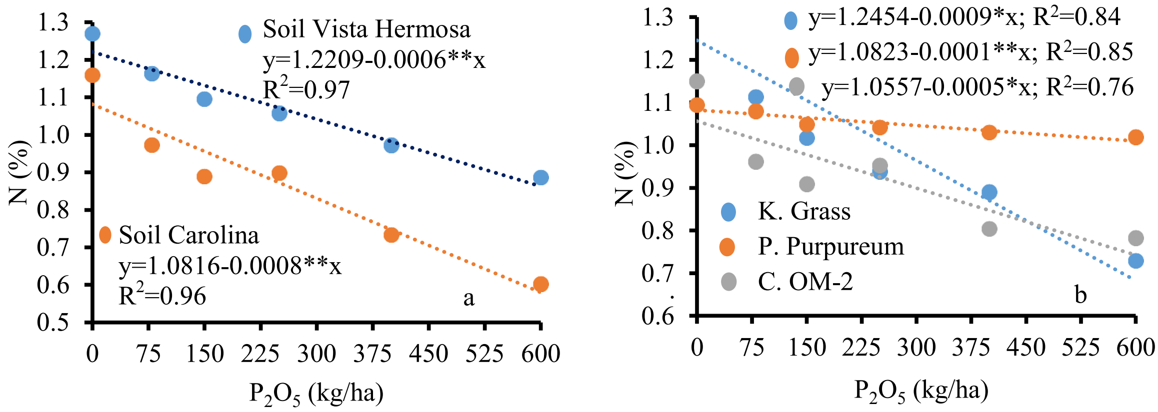

Figure 1. Foliar N content (%) as a function of the P_2O_5 dose for two calcareous soils (a) and three types of grass (b).

This nutrient absorption led to a greater gain in biomass from the elephant grass, with 464.67 g/experimental unit, followed by Cuba OM-22, with 451.07 g/experimental unit, and king grass, with 448.01 g/experimental unit. We observed a difference between the testicle treatment and the maximum dose of P applied with 6.8, 31.9, and 47.7%, respectively. This inverse relationship between growth and mineral concentration is the so-called “dilution effect” (JARRELL; BEVERLY, 1981). Santana et al. (2017) found that an increasing nitrogen application rate diminished leaf life because of the more pronounced plant growth and an increased dilution effect of nitrogen, as well as synergistic responses of specific mineral nutrients in Marandu grass.

The results of this study are in contrast to those found by Oliveira et al. (2010) for *Brachiaria brizantha* cv. *Marandu* and by Xu et al. (2016), who reported that different mixtures and levels of water and fertilizer supply, mainly N and P combined, affect the N and P concentrations in different organs of *B. ischaemum*. However, our results are similar to those reported by Silveira et al. (2015) for *Trifolium repens*, where there was saturation of foliar N from 38.8 kg ha^{-1} of P. In contrast, Silveira et al. (2015) reported an increase in N contents with P at the edaphic level in *Lotus tenuis.*

Phosphorus

The foliar phosphorus content responded to the interaction between calcareous soils and grasses (p-value $\leq$ 0.01) as well as to the interaction between calcareous soils and P doses (p-value $\leq$ 0.01) (Table 2). In the interaction between calcareous soils and grasses, the average foliar P in the Carolina soil was 0.61%, exceeding those of grasses in the Vista Hermosa soil by 53.98% (average 0.40%; Figure 2a). The average leaf biomass was 159.6 g in Vista Hermosa soil, compared to145.1 g in Carolina soil. This indicates a dilution effect of P in plant tissues (JARRELL; BEVERLY, 1981) as a consequence of increased biomass in the treatments with the highest P doses.

King grass presented the highest foliar P contents in the two calcareous soils. However, in Vista Hermosa soil, the average P levels in *Pennisetum purpureum* and king grass were 0.46%, 64.2% higher than the levels in Cuba OM-22 grass (0.28%). On the other hand, in the Carolina soil, the foliar P content of king grass (0.76%) differed by 24.5% and 68.8% to the values found for *Pennisetum purpureum* (0.61%) and Cuba OM-22 (0.45%) (Figure 2b). Menezes Júnior and Santos (2013) found similar P levels in *Brachiaria brizantha* cv. and *Pennisetum glaucum* L.

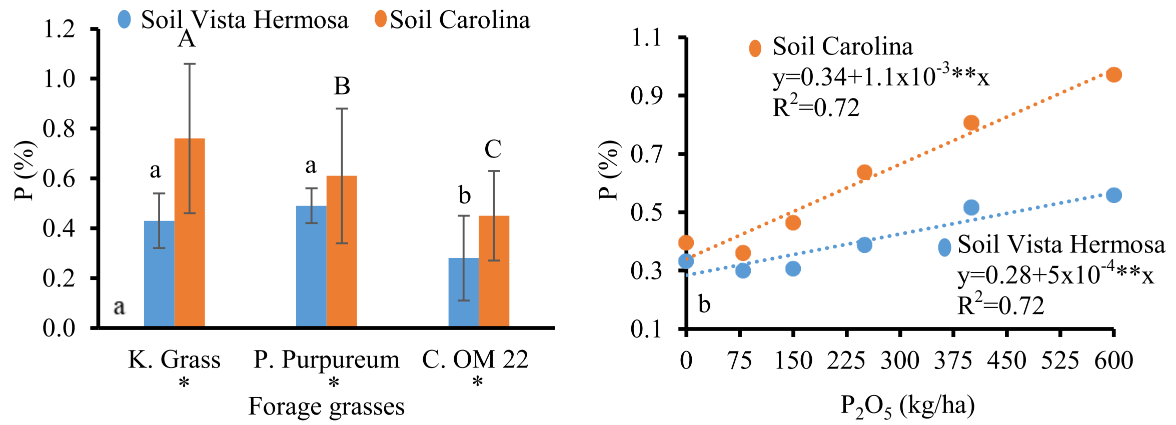

Figure 2. Foliar P contents of grasses grown in two calcareous soils (a) and as a function of P doses applied to the soil (b). The bars represent the means ± standard deviation, where the asterisks (*) indicate statistical differences between the two soils within each grass (p-value < 0.01). Lowercase and uppercase letters indicate differences among the grasses on Vista Hermosa and Carolina soils, respectively.

Regarding the interaction between calcareous soils and phosphorus doses (Figure 2b), the foliar P increased linearly with the edaphic P concentration. Grasses grown on Carolina soil showed a greater absorption and/or accumulation of P in response to the dilution effect (JARRELL; BEVERLY, 1981). The greater accumulation of P in grasses on Carolina soil cannot be explained by the reserve of available P because of the level of Ca (62.4 $cmol_c$ kg^{-1}), which can form insoluble compounds, reducing availability in the soil solution.

According to Han and Yin (2021), in calcareous soils, a high proportion of coarse fractions and calcium carbonate minerals in these fractions can fix large amounts of P, mainly via adsorption to the surface, causing them to precipitate mainly as dicalcium and tricalcium phosphates in high concentrations. However, according to Dilmaghani, Hemmaty and Naseri (2012), such soils have high levels of calcium carbonate equivalents and pH, leading to growth reduction, lower yields, nutrient deficiencies, and leaf chlorosis.

Potassium

The foliar potassium content was influenced by an interaction between calcareous soils and forage grasses (p-value $\leq$ 0.01), calcareous soils and phosphorus doses (p-value $\leq$ 0.08), and forage grasses and phosphorus doses (p-value $\leq$ 0.01). In addition, there was a triple interaction: calcareous soils-forage grasses-phosphorus dose (p-value $\leq$ 0.01) (Table 2).

In the interaction between calcareous soils and grasses, the foliar K content was on average 35.13% for *P. purpureum* and Cuba OM-22 grasses in Vista Hermosa, a value that exceeded 49.08% of the contents of the same pastures, but sown in the Carolina soil that presented the content of 23.52%. For the king grass pasture, the opposite response was observed; the highest content of foliar K was recorded in the Carolina soil with 24.26%, and in the V. Hermosa soil, the level was 20.44% (Figure 3a). In addition, the *P. purpureum* grass showed the highest accumulation of foliar K in both soils, with 38.88% and 26.59% for the V. Hermosa and Carolina soils, respectively (Figure 3a). When analyzing the K contents in the two soils, these were higher than the contents of 0.15% to 0.25% of foliar K reported by Silveira et al. (2015) for *Brachiaria* grass.

These foliar K contents may be associated with the K contents in the soils of the two sites; in Vista Hermosa, we found a K content of 1.15 $cmol_c\ kg^{-1}$, whereas in Carolina, the K level was 0.69 $cmol_c\ kg^{-1}$. In addition, the calcium contents were higher in the Carolina site, with 62.4 cmolc kg^{-1}, suggesting that there is an ionic antagonism in the soil solution that prevents the absorption of K by the grasses. In this study, *P. purpureum* absorbed a greater amount of K compared to the other grasses because of the more pronounced acidification in the rhizosphere of *P. purpureum*. Organic acids secreted by the roots are released into the rhizosphere, where they change the root microbial structure and the physical and chemical properties of soil and increase the dissolution rates of root nutrients, thereby promoting nutrient absorption by plants (ZHAO et al., 2016).

In the interactions between calcareous soils and P doses, as well as between forage grasses and P doses, the foliar K content decreased linearly with the application of P (Figures 3b and 3c). The K in the leaves of the grasses in the Carolina soil was less affected by the increase in P doses (Figure 3b), as was the *P. purpureum* (Figure 3c). This could be associated with the biomass gain in leaves in both sites, with 159.6 g for Vista Hermosa and 145.1 g for Carolina soil. These results may be related to the dilution effect (JARRELL; BEVERLY, 1981) as reduced concentrations of mineral nutrients were found in the leaves as the dry weight increased.

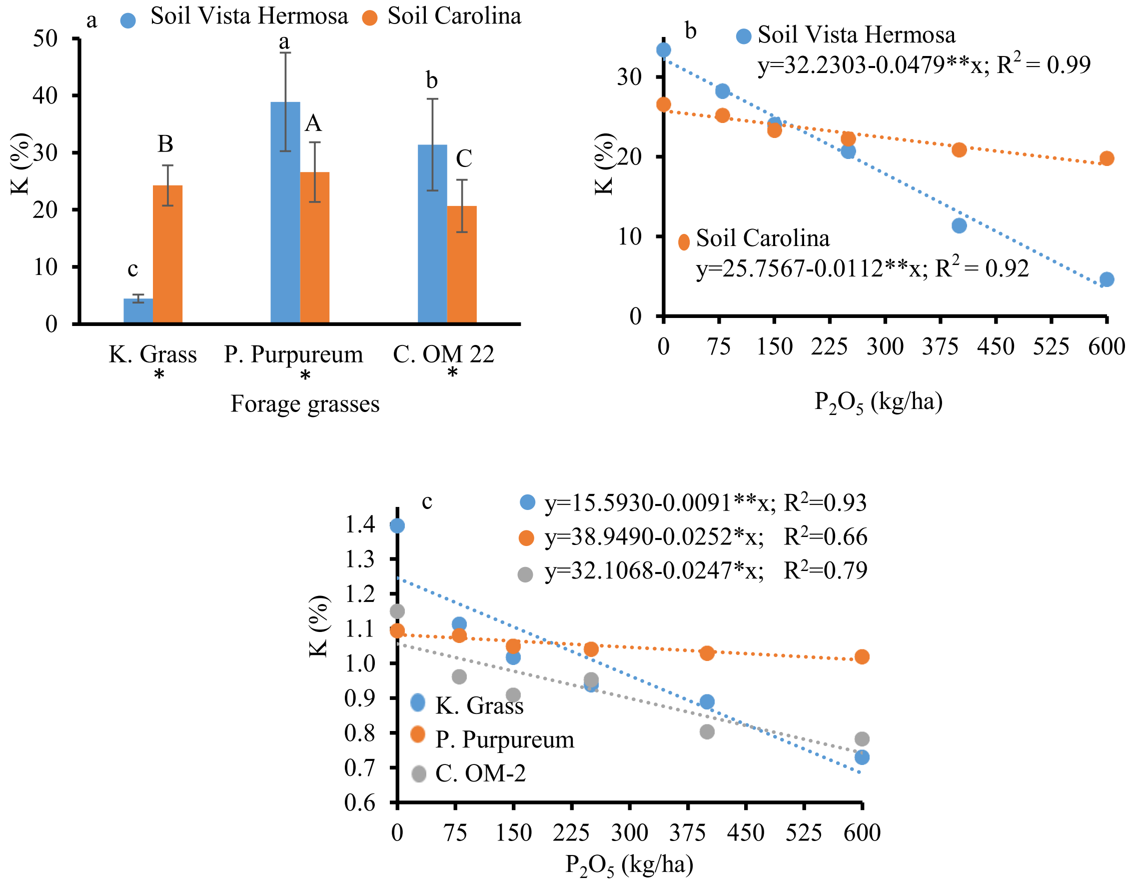

Figure 3. Foliar K content as a function of two calcareous soils and three grass types (a), two calcareous soils and the edaphic application of P (b), and three grass types and the edaphic application of P (c). The bars represent the means ± standard deviation, where the asterisks (*) indicate statistical differences between the two soils within each grass type; lowercase and uppercase letters indicate differences between forage grasses on Vista Hermosa and Carolina soils, respectively (p-value < 0.01).

Calcium

The amount of foliar calcium responded to the interaction between calcareous soils and forage grasses (p-value ≤ 0.01 between forage grasses and P doses (p-value = 0.05) and to the triple interaction: calcareous soils-forage pastures-P dose (p-value = 0. 03) (Table 2).

In the interaction between calcareous soils and forage grasses, the average content of foliar Ca in V. Hermosa soils for king grass and Cuba OM-22 pastures was 5.69%, which was 54.05% than the value found for Carolina soil (3.83%; Figure 4a). For king grass, we recorded a content of 5.86%, which is equivalent to an increase of 13.13% compared to *P. purpureum*, whose content was 5.18% on Carolina soil. In this soil, the foliar Ca of the king grass and *P. purpureum* was 4.88% on average, which was 60.16% higher than the content (3.05%) of Cuba OM-22 grass (Figure 4a). The foliar Ca concentrations observed here exceeded the values recorded by Magalhães et al. (2011) for *Brachiaria decumbens*, which were not higher than 1%.

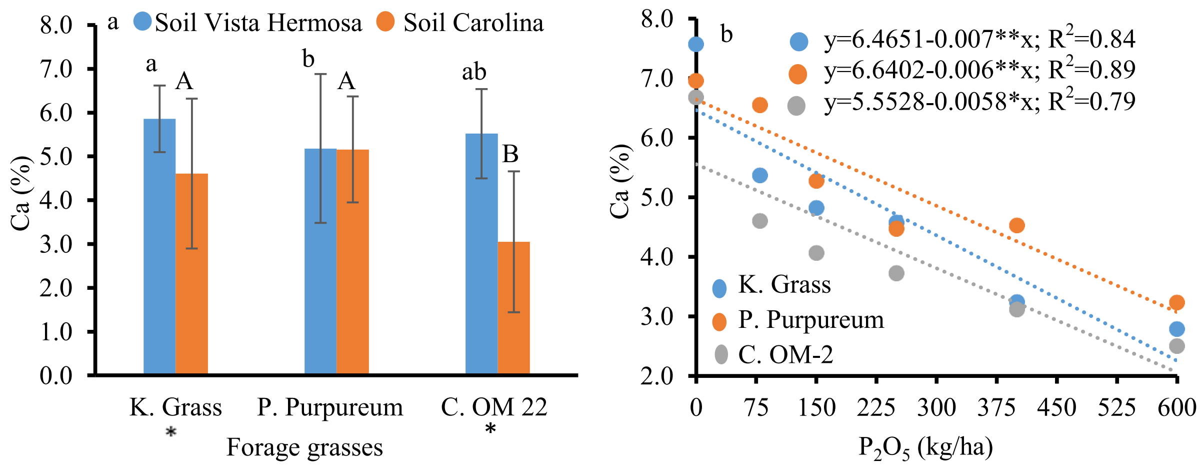

Figure 4. Foliar Ca content as a function of two calcareous soils and three grasses (a), three grass types, and the application of P (b). The bars represent the means ± standard deviation, where the asterisks (*) indicate statistical differences between the two soils within each grass type; lowercase and uppercase letters indicate differences between grass types on Vista Hermosa and Carolina soils, respectively (*p*-value < 0.01).

In accordance with Gerendás and Führs (2013), the high content of $CaCO_3$ causes issues such as a high pH and the loss of N by volatilization, low nutrient availability, particularly P, and nutritional imbalance between K and Mg with calcium. In addition, a higher concentration of Ca and K in soils significantly decreases the plant-availability of Mg. Both Ca and Mg showed an antagonistic relationship with the mobility of Mg, and one of the causes of the reduced yield levels is the deficiency or imbalance of nutrients.

In the interaction between grass types and P doses, the foliar Ca of all grasses decreased linearly with P application, where the king grass was the least affected species (Figure 4b), which also showed the highest Ca levels in both soils (Figure 4b). These results are associated with the biomass gain in pasture leaves in the two sites, caused by the dilution effect of Ca in the blades. Analyzing the contents of this element per kilogram of dry biomass for each grass, we found a decrease between the control treatment and the maximum dose of P applied, with 53.5%, 62.5%, and 63.1%, respectively (see also JARRELL; BEVERLY, 1981). According to Jin et al. (2013), plants can also change their nutrient allocation patterns under elevated CO_2 levels, and the resulting growth increases lead to higher demands for P, which is taken up from the available P pool in soil.

However, the decrease in Ca in this research differs from the findings of Freitas et al. (2011) in *Panicum maximum* Jacq, who attributed the decrease in foliar Ca with the increase in the P dose due to the dilution effect when the plant is more fertilized. Bouras et al. (2022), in *Panicum antidotale* at soil with a pH of 8.7, found no differences in foliar Ca concentration after applying between 0 and 108 kg/ha of P in the form of P_2O_5.

Magnesium

The foliar magnesium content was influenced by the interaction between calcareous soils and forage grasses (p-value ≤ 0.01), calcareous soils and phosphorus doses (p-value ≤ 0.01), forage grasses and phosphorus doses (p-value ≤ 0.01 ***), as well as by the triple interaction calcareous soils -forage grasses-phosphorus dose (p-value ≤ 0.02) (Table 2).

In the interaction between calcareous soils and phosphorus doses, there were differences in foliar Mg between calcareous soils for *P. purpureum*, where the content in V. Hermosa soil was 4.05%, exceeding the values for Carolina soil by10% (Figure 5a). In the V. Hermosa soil, *P. purpureum* stood out with 4.05% due to its high content of foliar Mg, with an increase by 17.39% with respect to the values found for king grass and Cuba OM-22 (average: 3.66%). However, in Carolina soil, there were no differences in Mg concentrations among grasses (Figure 5a). The amounts of foliar Mg found in this study exceeded the values reported by Magalhães et al. (2011) for *Brachiaria decumbens*, which were not higher than 1%.

In the interaction between calcareous soils and P doses (Figure 5b), the foliar Mg content of the grasses showed a tendency to decrease with increasing P doses in both soils.

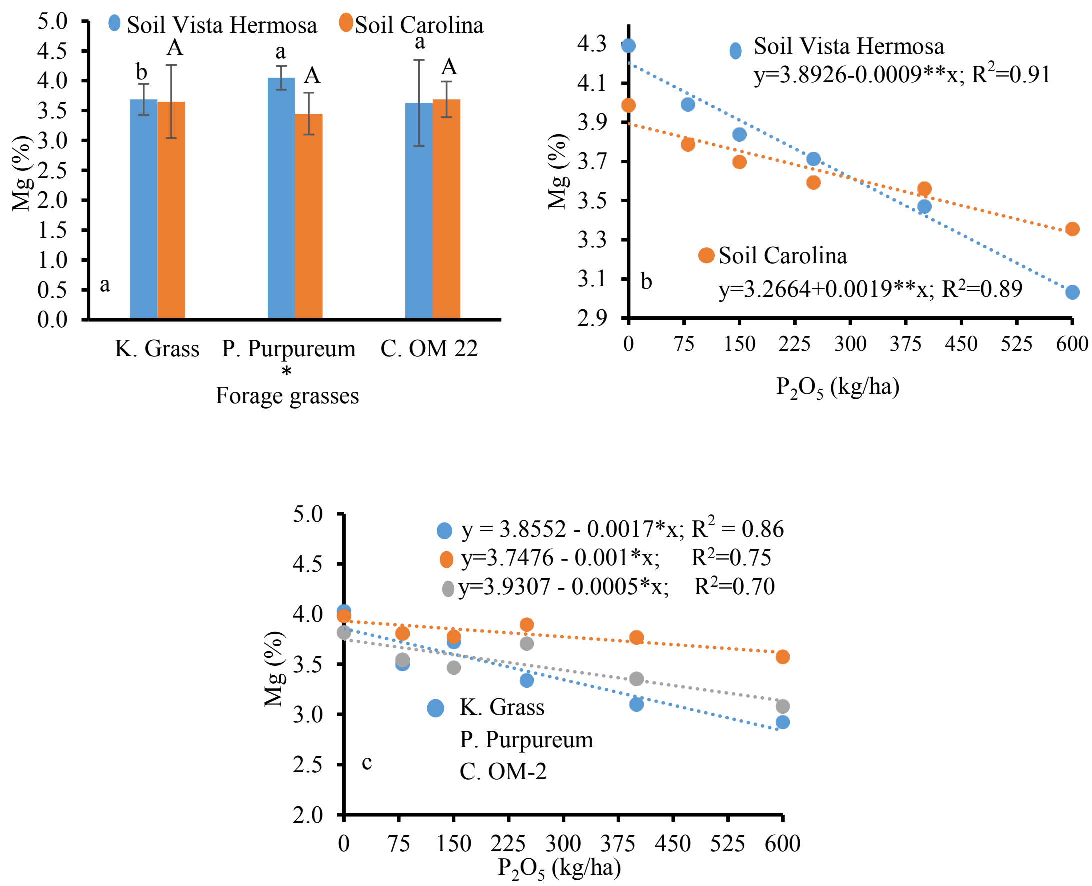

Figure 5. Foliar Mg content as a function of two calcareous soils and three forage grasses (a), two calcareous soils and the edaphic application of phosphorus (b), and three forage grasses and the edaphic application of phosphorus (c). The bars represent the means ± standard deviation, where the asterisks (*) indicate statistical differences between the two soils within each grass type; lowercase and uppercase letters indicate differences among forage grasses on Vista Hermosa and Carolina soils, respectively (p-value < 0.01).

In the interaction between forage grasses and P doses, the Mg content increased with increasing P doses, irrespective of the grass species (Figure 5c). However, *P. purpureum* presented the highest accumulation of foliar Mg and king grass the lowest one with increasing P doses. These findings may be associated with the biomass gain in the leaves of all three grasses, associated with the dilution effect of Mg in plant tissues (JARRELL; BEVERLY, 1981).

In calcareous soils, there are various interactions among different elements, with a nutritional imbalance among elements such as potassium, magnesium, and calcium (FREITAS et al., 2011), which may explain our findings.

Correlations of the foliar levels of P with N, K, Ca, and Mg

Correlation analysis suggests an antagonism between the foliar levels of P with N, K, Ca, and Mg in all three grasses and for both soils (Table 3). This is because we found that in plant fabrics the contents of N, K, Ca and Mg were greater in the treatments with a lower amount of applied P. Similarly, the contents of foliar P and the biomass increased with increasing P doses. This demonstrates that the greatest gain in foliar phosphorus diluted or reduced the levels of these elements in the biomass of all three grasses, with an average of 68.6%, 65.1%, 79.8%, and 40.7%, respectively, for N, K, Ca, and Mg, when the foliar contents of the testicle treatment and the maximum dose of phosphorus applied were contrasted (JARRELL; BEVERLY, 1981). In addition, under these soil conditions, with high pH and high Ca saturation, the formation of insoluble compounds, such as calcium phosphate, calcium sulfate, as well as Fe, Mn, Cu, and Zn hydroxides, is possible. Calcareous soils contain high levels of calcium carbonate ($CaCO_3$), which may also affect the mobility and bioavailability of macro- and micronutrients (TAALAB et al., 2019).

According to Hailu et al. (2015) there is usually an inverse and adverse relationship between a high concentration of one cation in the soil and the availability and uptake of other cations by the plant. That is, if Ca and/or Mg dominate the exchange complex over K, it may reduce K availability, potentially resulting in K deficiency.

Table 3. Pearson´s correlation of the foliar contents of P with N, K, Ca, and Mg.

Soils	Grass	N	K	Ca	Mg
Vista Hermosa	King Grass	-0.86*	-0.91**	-0.84*	-0.70
	Pennisetum purpureum	-0.94**	-0.94**	-0.98**	-0.26
	Cuba OM-22	-0.93**	-0.92**	-0.90*	-0.96**
Carolina	King Grass	-0.69	-0.95**	-0.60	-0.87*
	Pennisetum purpureum	-0.97**	-0.83*	-0.83*	-0.57
	Cuba OM-22	-0.07	-0.64	-0.64	-0.74°

**: Differences at 1%; *: Differences at 5%; °: Differences at 10%.

CONCLUSIONS

The application of phosphorus to calcareous soils did not increase the contents of N, K, Ca, and Mg in king grass, *Pennisetum purpureum*, and Cuba OM -22 pastures.

In the calcareous soils of Carolina, which have a higher natural calcium content, king grass, *Pennisetum purpureum*, and Cuba OM -22 pastures absorbed a greater amount of P.

King grass required high levels of P and Ca, whereas *Pennisetum purpureum* required high K levels in both soils and high Mg levels only in Vista Hermosa soil.

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