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Contents

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Abstract – Phosphorus (P) is a key nutrient for the establishment of intercropping between forage grasses and legumes. The objective of this work was to determine the requirement of P for the establishment of palisade grass and forage peanut grown in association under controlled conditions. A pot experiment was conducted in greenhouse using a randomized complete block design with eight treatments and four replicates. The treatments were the following P rates: 0 mg dm^{-3} (control), 80 mg dm^{-3}, 160 mg dm^{-3}, 240 mg dm^{-3}, 320 mg dm^{-3}, 400 mg dm^{-3}, and 560 mg dm^{-3} [source: $Ca(H_2PO_4)_2.H_2O$]. Palisade grass (*Urochloa brizantha* 'Marandu') and forage peanut (*Arachis pintoi* 'BRS Mandobi') were grown for 24 days after standardization cut and then cut at a 10-cm height for determination of the plant top dry matter. The suitable P supply for the plant top growth was different between the species. Palisade grass needed 80 mg P dm^{-3}, whereas 160 mg P dm^{-3} were required by the forage peanut. Forage peanut needed more P than palisade grass for the establishment of both species growing in association under controlled conditions.

Index terms: *Arachis pintoi*, intercropping, phosphate, *Urochloa brizantha*.

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Suprimento de fósforo para o estabelecimento de capim-braquiarão e amendoim forrageiro cultivados em associação

Resumo – Fósforo (P) é um nutriente-chave para o estabelecimento de consórcio de gramíneas e leguminosas forrageiras. O objetivo deste trabalho foi determinar a necessidade de P para o estabelecimento de capim-braquiarão e amendoim forrageiro cultivados em associação sob condições controladas. Um experimento de vasos foi conduzido em casa de vegetação usando o delineamento em blocos completos ao acaso com oito tratamentos e quatro repetições. Os tratamentos foram as seguintes doses de P: 0 mg dm^{-3} (controle), 80 mg dm^{-3}, 160 mg dm^{-3}, 240 mg dm^{-3}, 320 mg dm^{-3}, 400 mg dm^{-3} e 560 mg dm^{-3} [fonte: $Ca(H_2PO_4)_2.H_2O$]. Capim-braquiarão (*Urochloa brizantha* ‘Marandu’) e amendoim forrageiro (*Arachis pintoi* ‘BRS Mandobi’) foram cultivados por 24 dias depois do corte de uniformização e então cortados a 10 cm de altura para determinação da matéria seca do topo da planta. O suprimento adequado de P para o crescimento do topo da planta diferiu entre as espécies. Capim--braquiarão necessitou de 80 mg dm^{-3} de P, ao passo que 160 mg dm^{-3} de P foram exigidos pelo amendoim forrageiro. O amendoim forrageiro necessitou de mais P do que o capim-braquiarão para o estabelecimento de ambas as espécies cultivadas em associação sob condições controladas.

Termos para indexação: *Arachis pintoi*, consórcio, fosfato, *Urochloa brizantha.*

Introduction

Grass-legume pasture is a differential strategy for pastoral systems in the humid tropics. The presence of legume in pastures (i) improves the nutritive value of forage and consequently the animal performance (Lascano, 1994), (ii) stimulates the nitrogen (N) cycling (Cantarutti et al., 2002; Homem et al., 2021) reducing the need for N-fertilizer (Pereira et al., 2020), and increases the carbon sequestration in soil (Tarré et al., 2001). These benefits of forage legume make livestock farming more sustainable in the tropical environment.

One of the challenges for the success of a grass-legume pasture is the establishment of the plants. In this stage, phosphorus (P) is decisive, because it is directly involved in the root development (Mesquita et al., 2004b). As forage grasses and legumes differ in P requirement (Guss et al., 1990a, 1990b), the supply of P for both plants growing in association is still a matter of debate.

Studies on P supply for grass-legume pasture in Brazil are scarce, but the few that exist cover an interesting variety of species. The effects of P fertilization were studied in the following associations: *Brachiaria dictyoneura* + *Arachis pintoi*, *Stylosanthes capitata* or *Centrosema acutifolium*, in a greenhouse (Rao et al., 1995); and *Brachiaria decumbens* 'Basilisk' or *Brachiaria brizantha* 'Xaraés' + *Stylosanthes guianensis* 'Mineirão', in establishment of the pasture (Mesquita et al., 2004a; Lopes et al., 2011); and *B. brizantha* 'Marandu' + *A. pintoi* 'Belmonte', in pasture already established in field (Andrade et al., 2012). With the exception of this last association, in all the others the supply of P increased the forage production of grasses more than that of legumes. Consequently, the proportion of legumes decreased with P application, a result attributed to a greater ability of grasses to compete. However, the P rates in these studies may have been sufficient for grasses, but insufficient for the tested legumes, resulting in an additional competitive advantage for grasses at the expense of legumes.

We hypothesize that palisade grass and forage peanut growing associated will require different P supplies for their establishment. The objective of this work was to determine the requirement of P for the establishment of palisade grass and forage peanut grown in association under controlled conditions.

Material and Methods

The soil used in this study was classified according to Santos et al. (2018) as *Argissolo Amarelo Distrófico abrúptico, textura arenosa/média, A moderado, caulinítico, floresta equatorial subperenifólia, suave ondulado*. This soil was also classified according to Soil Taxonomy (Soil Survey Staff, 2014) as fine-loamy, kaolinitic, isohyperthermic Typic Kandiudult. Samples from the surface soil layer (0–20-cm depth) were collected, air-dried, sieved (9-mm sieve), homogenized, and submitted to chemical and physical analyses for determination of selected soil fertility attributes, soil particle size, and total porosity (P_t). These analyses reveled pH (H_2O) 5.38, pH ($CaCl_2$) 4.20, organic C = 14.36 g kg^{-1}, Mehlich-1 P = 5.4 mg dm^{-3}, resin P = 11.4 mg dm^{-3}, K = 0.03 cmol$_c$ dm^{-3}, Ca = 0.2 cmol$_c$ dm^{-3}, Mg = 0.1 cmol$_c$ dm^{-3}, Al = 1.4 cmol$_c$ dm^{-3}, H+Al = 6.4 cmol$_c$ dm^{-3}, CEC at pH 7 = 6.73 cmol$_c$ dm^{-3}, base saturation = 4.9%, SO_4^{2-}–S = 6.5 mg dm^{-3}, hot-water soluble B = 0.33 mg dm^{-3}, DTPA Cu = 0.1 mg dm^{-3}, DTPA Fe = 137 mg dm^{-3}, DTPA Mn = 0.2 mg dm^{-3}, DTPA Zn = 0.1 mg dm^{-3}, sand = 845 g kg^{-1}, silt = 95 g kg^{-1}, clay = 60 g kg^{-1} and P_t = 0.412 dm^3 dm^{-3}. The chemical and physical analyses were performed according to Silva et al. (2009) and Donagemma et al. (2017), respectively.

Thirty-two plastic pots (17-cm lower diameter, 21-cm upper diameter, 17-cm height, and capacity for 4.9 L) were filled each with 4.8 dm^3 of soil. Adequate quantities of $CaCO_3$ and $MgCO_3$ [4:1 (w/w) Ca:Mg ratio] were mixed with soil of each pot. The soil was then moistened with distilled water at 70% of the P_t and incubated for 30 days. This application of carbonates was performed to raise the soil pH (H_2O) to a range of 5.5-6.0, which seems to be suitable for both palisade grass (Cruz et al., 1994) and forage peanut (Rao; Kerridge, 1994).

After the incubation with carbonates, the soil of each pot was fertilized with the following rates and sources of nutrients: 50 mg N dm^{-3} [$CO(NH_2)_2$], P according to treatments, 50 mg K dm^{-3} (K_2SO_4), 24.3 mg S dm^{-3} (K_2SO_4, $CuSO_4.5H_2O$, $MnSO_4.H_2O$ and $ZnSO_4.H_2O$), 0.5 mg B dm^{-3} (H_3BO_3), 1 mg Cu dm^{-3} ($CuSO_4.5H_2O$), 4 mg Mn dm^{-3} ($MnSO_4.H_2O$), 0.16 mg Mo dm^{-3} ($Na_2MoO_4.2H_2O$) and 2 mg Zn dm^{-3} ($ZnSO_4.H_2O$). The P rates (i.e., treatments) were 0 mg dm^{-3} (control), 80 mg dm^{-3}, 160 mg dm^{-3}, 240 mg dm^{-3}, 320 mg dm^{-3}, 400 mg dm^{-3} and 560 mg dm^{-3}, using $Ca(H_2PO_4)_2.H_2O$ as a source. These P rates were based on previous studies conducted with palisade grass (Guss et al., 1990a) and some forage legumes (Guss et al., 1990b), including forage peanut (Costa et al., 2006), all these plants grown separately in pots within greenhouses. These studies, the suggestions from Novais et al. (1991), as well as the results of soil analyses were used to define rates for the other nutrients. The nutrient sources were mixed with soil, which was again moistened with distilled water at 70% of the P_t and incubated for further 15 days. We used as carbonates and sources of nutrients reagent grade chemicals. Carbonates and the P source were mixed with soil at dry. The other nutrients were supplied with nutrient solution.

After the incubation with nutrient sources, the soil was air-dried, homogenized, and sampled. The sampling was performed by collecting 0.400 dm^3 of soil from each pot. Then the collected soil was passed through a 2-mm sieve and analyzed for P using Mehlich-1 and resin extractants, according to procedures described in Silva et al. (2009).

Seeds of palisade grass [*Urochloa brizantha* (Hochst. ex A. Rich.) R. Webster 'Marandu'] and forage peanut (*Arachis pintoi* Krapov. & W.C. Greg. 'BRS Mandobi') were sown at a 1-cm depth. The seeds of the two species were intercalated and equidistant from each other in order to obtain four plants of palisade grass and four plants of forage peanut. We used a plastic plate perforated at the position of each seed to guide us in sowing (Figure 1). This procedure was adopted to uniform the spatial distribution of seeds in the pot. Forage peanut seeds were previously treated with ethephon to overcome dormancy (Assis et al., 2015). Occasional reseeding was performed to replace failed seeds.

Photos: Alysson Roberto Baizi e Silva

Figure 1. Sowing using a plastic plate perforated at the position of each seed (C: palisade grass seed; L: forage peanut seed).

A standardization cut of plants was performed 46 days after sowing. This relatively long time was required for forage peanut to grow. Plants were cut to a 10-cm height. Because of the creeping growth habit, forage peanut was positioned vertically in relation to the soil level in the pot before cutting. Immediately after this cut, 50 mg N dm^{-3} [reagent grade $CO(NH_2)_2$] and 50 mg K dm^{-3} (reagent grade KCl) were applied to the soil of all pots as a nutrient solution. Throughout the growth period of the forage plants, the soil of each pot was moistened with distilled water at 70% of the P_t three times a week to replenish the water lost by evapotranspiration.

Plants were grown for 24 days when they were again cut at 10-cm height (Figure 2). This was considered to be the first cut of the forage plants. Plant material was passed in tap water (two times) and distilled water (one time), oven-dried at 70 °C and weighted for determination of the plant top dry matter (i.e., material harvested above 10-cm plant height).

Photo: Alysson Roberto Baizi e Silva

Figure 2. Cut of palisade grass top at a 10-cm height in relation to the soil level in the pot.

The experiment was conducted in a randomized complete block design with eight treatments (P rates) and four replicates. Data of each variable were analyzed using a two-way analysis of variance (Anova). When Anova was significant, regression analysis was performed. When there was no regression adjustment, means were compared by the Fisher's least significant difference (LSD). Regression was also used to describe the relationship between Mehlich-1 P and resin P. All analyses were performed in R (R Core Team, 2021) at $P < 0.05$.

Results and Discussion

There were no significant effects of P rates on both pH in H_2O and pH in $CaCl_2$ (Table 1), indicating that the applied P did not change the soil acidity. We determined the pH because we suspected that P applied at high rates could increase the soil pH, since this effect has been reported in the literature (Barrow et al., 2021). The increase in pH occurs due to the displacement of hydroxyl (OH^-) ions from the surface of soil variable charge particles with the sorption of applied phosphate (Rajan, 1975). As the soil used in our study was poor in clay (60 g kg^{-1}), we believe that P sorption was low, and therefore little OH^- ions were released, insufficient to change the pH. Thus, possible effects of P rates on growth of palisade grass and forage peanut in the present work could not be attributed to changes in soil pH supposedly induced by applied P. The overall average pH in H_2O was 6.0, that is, within the expected range (see in Material and Methods).

Another factor that could affect the growth of the forage plants as an indirect effect of P rates is the increase in S availability in the soil. Table 1 shows that the applied P significantly increased the SO_4^{2-}–S concentration. This increase may have occurred due to decrease in applied sulfate adsorption and increase in sulfate desorption, both induced by applied phosphate. These two mechanisms have been demonstrated experimentally (Barrow; Debnath, 2015). However, we believe that the increase observed in SO_4^{2-}–S concentration did not influence the growth of palisade grass and forage peanut, because the SO_4^{2-}–S concentration in the control was already high, well above the critical levels for cultivated plants in Brazil (Kliemann; Malavolta, 1993; Pias et al., 2019).

Table 1. Effect of P rates on selected soil fertility attributes before sowing palisade grass and forage peanut.

P rate (mg dm^{-3})	pH (H_2O)	pH ($CaCl_2$)	SO_4^{2-}–S	Mehlich-1 P	Resin P
			(mg dm^{-3})		
0	6.1	5.7	32 b	2	10
80	6.1	5.8	36 a	24	23
160	6.0	5.8	36 a	62	37
240	6.1	5.8	37 a	105	61
320	5.8	5.7	38 a	149	105
400	6.0	5.7	37 a	202	135
480	6.0	5.8	39 a	265	167
560	5.9	5.7	38 a	308	203
SEM	0.1	0.1	1	6	6
P-value (Anova)	0.056	0.782	0.001	< 0.001	< 0.001

SEM: standard error of the mean.
Different letters within a column indicate significant difference between means according to the LSD ($P < 0.05$).

P rates significantly and progressively increased the concentration of P extracted from the soil with Mehlich-1 and resin (Table 1). The increase in P extracted with each extractant was better described by a quadratic regression equation (concave relationship). The regression equations for both extractants are these:

Mehlich-1 P | $\hat{y} = -2.5208 + 0.3583x + 0.0004x^2$ | P-value < 0.001 | $R^2 = 0.9977$ (1)

Resin P | $\hat{y} = 6.3042 + 0.1829x + 0.0003x^2$ | P-value < 0.001 | $R^2 = 0.9932$ (2)

in which, $\hat{y}$ is the concentration of Mehlich-1 P or resin P in the soil (mg dm^{-3}), and x is the P rate applied to the soil (mg dm^{-3}), within the application range of 0 mg P dm^{-3} to 560 mg P dm^{-3}.

Where P was applied, the Mehlich-1 P concentrations were higher than those of resin P (Table 1). This effect has been observed in soil with low clay content (160 g kg^{-1}), as the soil used in our study (clay = 60 g kg^{-1}), and it is due to low phosphate buffer capacity (Reis et al., 2020). Despite this difference, concentrations of P by both extractants were highly correlated (Figure 3). The linear regression equation that describes this relationship (Figure 3) is useful to estimate for this soil the concentration of P extracted by one extractant having the concentration of P extracted by the other extractant. For both extractants, application of P to the soil created a wide range of extractable P (Table 1), which is desirable for evaluating plant response to applied P.

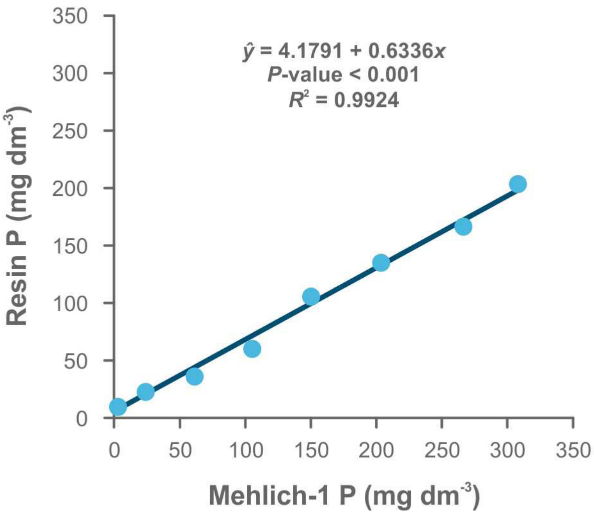

Figure 3. Relationship between P extracted with Mehlich-1 and P extracted with resin from the soil used in this study.

Palisade grass and forage peanut grown in association significantly responded to P rates (Table 2). Palisade grass top dry matter increased (13-fold) with 80 mg P dm^{-3}, declined somewhat with 160 mg P dm^{-3} and 240 mg P dm^{-3}, and reached a minimum with 320 mg P dm^{-3}. Forage peanut top dry matter increased (3.2-fold) with a higher P rate, 160 mg P dm^{-3}, and was stable up to 320 mg P dm^{-3}. This suggests that forage peanut P requirement was greater than that of palisade grass in the range of P rates from 0 mg P dm^{-3} to 320 mg P dm^{-3}. Rates above 320 mg P dm^{-3} markedly increased the grass top dry matter and decreased legume top dry matter, indicating that high P supply favored the grass over the legume. Santos et al. (2002) found similar response of forage peanut (cultivar Amarillo) grown in association with palisade grass (cultivar MG-4) to P supply. These authors observed that legume top dry matter increased with low-moderate P rates and decreased with high P rates. On the other hand, they did not notice a decrease in grass dry matter with increasing P rate. As this decrease occurred in our study, we suggested that forage peanut might be highly competitive with palisade grass depending on the P rate. Rates ranging from 80 mg P dm^{-3} to 320 mg P dm^{-3} increased the competitive capacity of forage peanut, while rates above 320 mg P dm^{-3} were much more favorable to the competition of palisade grass (Figure 4). The decrease in competitive capacity of forage peanut at high P rates may have been caused by P toxicity. Although rare, P toxicity has been observed in other forage legumes grown at high P (Pang et al., 2010). Further experiment should be conducted to determine toxic P levels in tissues of forage peanut.

Table 2. Effect of P rates on plant top dry matter of palisade grass, forage peanut, and palisade grass + forage peanut at the first cut.

P rate (mg dm^{-3})	Plant top dry matter			
	Palisade grass	Forage peanut	Palisade grass + forage peanut	% forage peanut
	(g per pot)			
0	0.8 c	1.5 b	2.3 b	65
80	10.2 ab	3.2 ab	13.5 a	24
160	8.6 ab	4.8 a	13.4 a	36
240	8.6 ab	4.8 a	13.3 a	36
320	6.0 bc	5.0 a	11.0 a	45
400	11.5 ab	3.1 ab	14.6 a	21
480	13.3 a	1.6 b	14.9 a	11
560	12.8 a	1.9 b	14.6 a	13
SEM	2.2	0.7	1.7	–
P-value (Anova)	0.011	0.003	0.001	–

SEM: standard error of the mean.

Different letters within a column indicate significant difference between means according to the LSD ($P < 0.05$).

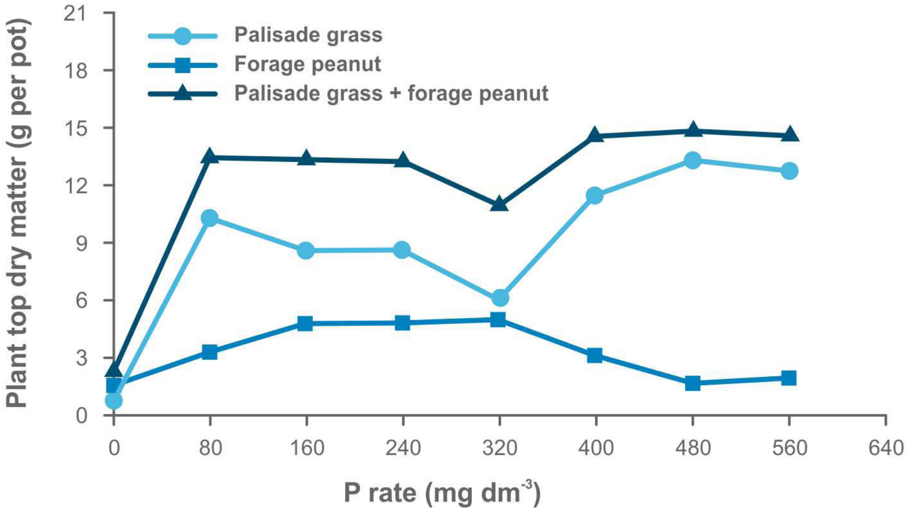

Figure 4. Response of plant top dry matter for palisade grass, forage peanut, and palisade grass + forage peanut to P rates. Results of statistical analysis are shown in Table 2.

Regardless of the applied P rate, palisade grass top dry matter was greater than that of forage peanut, indicating that the grass was more responsive to P application than the legume. This behavior was also observed by Rao et al. (1995) for *Brachiaria dictyoneura* grown in association with forage peanut.

Figure 5 shows relationships between top dry matter of the forage plants and P in the soil. These relationships mirrored well those ones in Figure 4. The greater palisade grass top dry matter was associated with the mean P concentrations of 24 mg dm^{-3} and 23 mg dm^{-3} for Mehlich-1 and resin, respectively (Figure 5). Satisfactory forage peanut top dry matter was obtained with higher mean P concentrations in the soil, 62 mg dm^{-3} and 37 mg dm^{-3} for Mehlich-1 and resin, respectively (Figure 5). This Mehlich-1 P concentration for the legume peanut is much lower than the critical P level (174 mg dm^{-3}) determined for another forage legume (*Centrosema* spp. 'Epamig 1111') grown in monoculture in a soil with 190 g kg^{-1} of clay (Guss et al., 1990b). Suitable concentrations of Mehlich-1 P and resin P for palisade grass and forage peanut are well above the interpretation limits of high P concentrations for the Cerrado region (Sousa et al., 2007). On the other hand, suitable concentrations of resin P for both species are interpreted as "medium" according to the criteria adopted in the state of São Paulo (Quaggio et al., 2022). Therefore, resin P interpretation by the São Paulo criteria seems to be more appropriate to the present work.

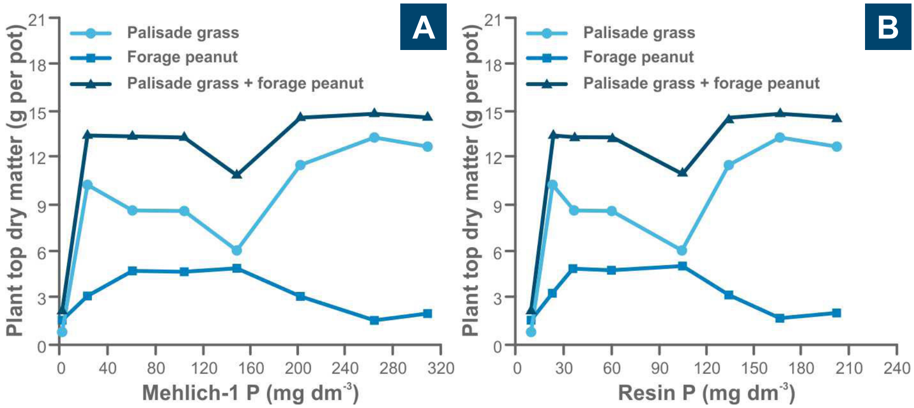

Figure 5. Response of plant top dry matter for palisade grass, forage peanut, and palisade grass + forage peanut to variation of Mehlich-1 P (A) and resin P (B) in the soil.

Conclusion

The suitable P supply for the plant top growth was different between the species. Palisade grass needed 80 mg P dm^{-3}, whereas 160 mg P dm^{-3} were required by the forage peanut. Forage peanut needed more P than palisade grass for the establishment of both species growing in association under controlled conditions.

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References

ANDRADE, C. M. S. de; GARCIA, R.; VALENTIM, J. F. Productivity, utilization efficiency and sward targets for mixed pastures of marandugrass, forage peanut and tropical kudzu. **Revista Brasileira de Zootecnia**, v. 41, n. 3, p. 512-520, 2012. Doi: https://doi.org/10.1590/S1516-35982012000300006

ASSIS, G. M. L. de; KRZYZANOWKI, F. C.; AZEVEDO, H. N. de. **Superação de dormência em sementes de amendoim forrageiro cv. BRS Mandobi**. Rio Branco, AC: Embrapa Acre, 2015. 7 p. (Embrapa Acre. Circular técnica, 70).

BARROW, N. J.; DEBNATH, A. Effect of phosphate status and pH on sulphate sorption and desorption. **European Journal of Soil Science**, v. 66, n. 2, p. 286-297, 2015. Doi: https://doi.org/10.1111/ejss.12223

BARROW, N. J.; DEBNATH, A.; SEN, A. Effect of pH and prior treatment with phosphate on the rate and amount of reaction of soils with phosphate. **European Journal of Soil Science**, v. 72, n. 1, p. 243-253, 2021. Doi: https://doi.org/10.1111/ejss.12968

CANTARUTTI, R.; TARRÉ, R.; MACEDO, R.; CADISCH, G.; REZENDE, C. P. de; PEREIRA, J. M.; BRAGA, J. M.; GOMIDE, J. A.; FERREIRA, E.; ALVES, B. J. R.; URQUIAGA, S.; BODDEY, R. M. The effect of grazing intensity and the presence of a forage legume on nitrogen dynamics in *Brachiaria* pastures in the Atlantic forest region of the south of Bahia, Brazil. **Nutrient Cycling in Agroecosystems**, v. 64, n. 3, p. 257-271, 2002. Doi: https://doi.org/10.1023/A:1021415915804

COSTA, N. de L.; PAULINO, V. T.; TOWNSEND, C. R.; MAGALHÃES, J. A. Resposta de *Arachis pintoi* cv. Amarillo a níveis de fósforo. **Revista de Biologia e Ciências da Terra**, v. 6, n. 1, p. 59-62, 2006.

CRUZ, M. C. P. da; FERREIRA, M. E.; LUCHETTA, S. Efeito da calagem sobre a produção de matéria seca de três gramíneas forrageiras. **Pesquisa Agropecuária Brasileira**, v. 29, n. 8, p. 1303-1312, 1994.

DONAGEMMA, G. K.; VIANA, J. H. M.; ALMEIDA, B. G. de; RUIZ, H. A.; KLEIN, V. A.; DECHEN, S. C. F.; FERNANDES, R. B. A. Análise granulométrica. In: TEIXEIRA, P. C.; DONAGEMMA, G. K.; FONTANA, A.; TEIXEIRA, W. G. (ed.). **Manual de métodos de análise de solo**. 3. ed. rev. e ampl. Brasília, DF: Embrapa, 2017. p. 95-116.

GUSS, A.; GOMIDE, J. A.; NOVAIS, R. F. de. Exigência de fósforo para o estabelecimento de quatro espécies de *Brachiaria* em solos com distintas características físico-químicas. **Revista da Sociedade Brasileira de Zootecnia**, v. 19, n. 4, p. 278-289, 1990a.

GUSS, A.; GOMIDE, J. A.; NOVAIS, R. F. de. Exigência de fósforo para o estabelecimento de quatro leguminosas forrageiras tropicais em solos com distintas características físico-químicas. **Revista da Sociedade Brasileira de Zootecnia**, v. 19, n. 5, p. 450-458, 1990b.

HOMEM, B. G. C.; LIMA, I. B. G. de; SPASIANI, P. P.; GUIMARÃES, B. C.; GUIMARÃES, G. D.; BERNARDES, T. F.; REZENDE, C. de P.; BODDEY, R. M.; CASAGRANDE, D. R. N-fertiliser application or legume integration enhances N cycling in tropical pastures. **Nutrient Cycling in Agroecosystems**, v. 121, n. 2-3, p. 167-190, 2021. Doi: https://doi.org/10.1007/s10705-021-10169-y

KLIEMANN, H. J.; MALAVOLTA, E. Disponibilidade de enxofre em solos brasileiros. III. Avaliação do enxofre-sulfato disponível por extratores químicos. **Anais da Escola de Agronomia e Veterinária**, v. 23, n. 1, p. 165-186, 1993.

LASCANO, C. E. Nutritive value and animal production of forage Arachis. In: KERRIDGE, P. C.; HARDY, B. (ed.). **Biology and agronomy of forage *Arachis***. Cali: Centro Internacional de Agricultura Tropical, 1994. p. 109-121.

LOPES, J.; EVANGELISTA, A. R.; PINTO, J. C.; QUEIROZ, D. S.; MUNIZ, J. A. Doses de fósforo no estabelecimento de capim-xaraés e estilosantes Mineirão em consórcio. **Revista Brasileira de Zootecnia**, v. 40, n. 12, p. 2658-2665, 2011. Doi: https://doi.org/10.1590/S1516-35982011001200007

MESQUITA, E. F.; FONSECA, D. M. da; PINTO, J. C.; NASCIMENTO JUNIOR, D. do; PEREIRA, O. G.; VENEGAS, V. H. A.; MOREIRA, L. de M. Estabelecimento de pastagem consorciada com aplicação de calcário, fósforo e gesso. **Ciência e Agrotecnologia**, v. 28, n. 2, p. 428-436, 2004a. Doi: https://doi.org/10.1590/S1413-70542004000200025

MESQUITA, E. E.; PINTO, J. C.; FURTINI NETO, A. E.; SANTOS, Í. P. A. dos; TAVARES, V. B. Teores críticos de fósforo em três solos para o estabelecimento de capim-mombaça, capim-marandu e capim-andropogon em vasos. **Revista Brasileira de Zootecnia**, v. 33, n. 2, p. 290-301, 2004b. Doi: https://doi.org/10.1590/S1516-35982004000200004.

NOVAIS, R. F.; NEVES, J. C. L.; BARROS, N. F. Ensaio em ambiente controlado. In: OLIVEIRA, A. J.; GARRIDO, W. E.; ARAÚJO, J. D.; LOURENÇO, S. (coord.). **Métodos de pesquisa em fertilidade do solo**. Brasília, DF: EMBRAPA-SEA, 1991. p. 189-198. (EMBRAPA-SEA. Documentos, 3).

PANG, J.; RYAN, M. H.; TIBBETT, M.; CAWTHRAY, G. R.; SIDDIQUE, K. H. M.; BOLLAND, M. D. A.; DENTON, M. D.; LAMBERS, H. Variation in morphological and physiological parameters in herbaceous perennial legumes in response to phosphorus supply. **Plant and Soil**, v. 331, n. 1-2, p. 241-255, 2010. Doi: https://doi.org/10.1007/s11104-009-0249-x

PEREIRA, J. M.; REZENDE, C. de P.; BORGES, A. M. F.; HOMEM, B. G. C.; CASAGRANDE, D. R.; MACEDO, T. M.; ALVES, B. J. R.; SANT'ANNA, S. A. C. de; URGUIAGA, S.; BODDEY, R. M. Production of beef cattle grazing on *Brachiaria brizantha* (Marandu grass)—*Arachis pintoi* (forage peanut cv. Belomonte) mixtures exceeded that on grass monocultures fertilized with 120 kg N/ha. **Grass and Forage Science**, v. 75, n. 1, p. 28-36, 2020. Doi: https://doi.org/10.1111/gfs.12463

PIAS, O. H. de C.; TIECHER, T.; CHERUBIN, M. R.; MAZURANA, M.; BAYER, C. Crop Yield responses to sulfur fertilization in Brazilian no-till soils: a systematic review. **Revista Brasileira de Ciência do Solo**, v. 43, e0180078, 2019. Doi: https://doi.org/10.1590/18069657rbcs20180078

QUAGGIO, J. A.; MATTOS JUNIOR, D.; RAIJ, B. van. Fósforo. In: CANTARELLA, H.; QUAGGIO, J. A.; MATTOS JUNIOR, D.; BOARETTO, R. M.; RAIJ, B. van (ed.). **Boletim 100**: Recomendações de adubação e calagem para o estado de São Paulo. Campinas: Instituto Agronômico, 2022. p. 95-105.

RAJAN, S. S. S. Adsorption of divalent phosphate on hydrous aluminum oxide. **Nature**, v. 253, p. 434-436, 1975. Doi: https://doi.org/10.1038/253434a0

R CORE TEAM. **R**: A language and environment for statistical computing (Version 4.1.1). [S.l.]: R Foundation for Statistical Computing, 2021.

RAO, I. M.; BORRERO, V.; AYARZA, M. A.; GARCIA, R. Adaptation of tropical forage species to acid soils: the influence of varying phosphorus supply and soil type on plant growth. In: DATE, R. A.; GRUNDON, N. J.; RAYMENT, G. E.; PROBERT, M. E. (ed.). **Plant-soil interactions at low pH**: principles and management. Dordrecht: Springer, 1995. p. 235-241. Doi: https://doi.org/10.1007/978-94-011-0221-6_32

RAO, I. M.; KERRIDGE, P. C. Mineral nutrition of forage Arachis. In: KERRIDGE, P. C.; HARDY, B. (ed.). **Biology and agronomy of forage *Arachis***. Cali: Centro Internacional de Agricultura Tropical, 1994. p. 71-83.

REIS, J. V. dos; ALVAREZ V., V. H.; DURIGAN, R. D.; PAULUCIO, R. B.; CATARUTTI, R. B. Interpretation of soil phosphorus availability by Mehlich-3 in soils with contrasting phosphorus buffering capacity. **Revista Brasileira de Ciência do Solo**, v. 44, e0190113, 2020. Doi: https://doi.org/10.36783/18069657rbcs20190113.

SANTOS, H. G.; JACOMINE, P. K. T.; ANJOS, L. H. C.; OLIVEIRA, V. A.; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A.; ARAÚJO FILHO, J. C.; OLIVEIRA, J. B.; CUNHA, T. J. F. **Sistema brasileiro de classificação de solos**. 5. ed. rev. ampl. Brasília, DF: Embrapa, 2018. 356 p.

SANTOS, Í. P. A. dos; PINTO, J. C.; SIQUEIRA, J. O.; MORAIS, A. R. de; SANTOS, V. L. dos. Influência do fósforo, micorriza e nitrogênio no conteúdo de minerais de *Brachiaria brizantha* e *Arachis pintoi* consorciados. **Revista Brasileira de Zootecnia**, v. 31, n. 2, p. 605-616, 2002. Doi: https://doi.org/10.1590/S1516-35982002000300010.

SILVA, F. C. da; ABREU, M. F. de; PÉREZ, D. V.; EIRA, P. A. da; ABREU, C. A. de; RAIJ, B. van; GIANELLO, C.; COELHO, A. M.; QUAGGIO, J. A.; TEDESCO, M. J.; SILVA, C. A.; CANTARELLA, H.; BARRETO, W. de O. Métodos de análises químicas para avaliação da fertilidade do solo. In: SILVA, F. C. da (ed.). **Manual de análises químicas de solos, plantas e fertilizantes**. 2. ed. rev. ampl. Brasília, DF: Embrapa Informação Tecnológica, 2009. p. 107-189.

SOIL SURVEY STAFF. **Keys to Soil Taxonomy**. 12. ed. Washington: USDA-NRCS, 2014. 360 p.

SOUSA, D. M. G. de; MARTHA JÚNIOR, G. B.; VILELA, L. Adubação fosfatada. In: MARTHA JÚNIOR, G. B.; VILELA, L.; SOUSA, D. M. G. de. (ed.). **Cerrado**: uso eficiente de corretivos e fertilizantes em pastagens. Planaltina: Embrapa Cerrados, 2007. p. 145-177.

TARRÉ, R.; MACEDO, R.; CANTARUTTI, R. B.; REZENDE, C. P. de; PEREIRA, J. M.; FERREIRA, E.; ALVES, B. J. R.; URQUIAGA, S.; BODDEY, R. M. The effect of the presence of a forage legume on nitrogen and carbon levels in soils under *Brachiaria* pastures in the Atlantic forest region of the South of Bahia, Brazil. **Plant and Soil**, v. 234, n. 1, p. 15-26, 2001. Doi: https://doi.org/10.1023/A:1010533721740

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