Phosphorus availability in an Oxisol in pastures grown in Southern Brazilian Amazonia

Disponibilidade de fósforo em solos oxídicos em pastagens cultivadas no sul da Amazônia brasileira

Disponibilidad de fósforo en un oxisol en pastos cultivados en el sur de la Amazonía brasileña

Received: 07/25/2022 | Reviewed: 08/03/2022 | Accept: 08/05/2022 | Published: 08/15/2022

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Abstract

The objective of this study was to verify and compare the P availability in an Oxisol cultivated with *Megathyrsus maximus* cv BRS-Zuri and *Urochloa decumbens* cv Basilisk and to predict the best soil P extractor in pastures in Southern Amazonia. Two experiments were carried out, one with BRS-Zuri grass and the other with Signal grass. The experimental design was randomized blocks with five doses of P_2O_5 based on the maximum capacity of adsorption of P (MCAP), corresponding to 0, 3, 6, 12 and 24% MCAP, with doses 0, 54, 108, 216 and 432 kg ha^{-1} of P_2O_5, with four replicates. In each cut of the grasses were determined the dry mass, the accumulation of leaf P and by the Mehlich-1 and resin extractors verified the available P. There were effects of P_2O_5 doses on the variables analyzed in both grasses. The appropriate class of P by Mehlich-1 was 14.6 mg dm^{-3} (BRS-Zuri) and 7.2 (*U. decumbens*) mg dm-3, by the resin extractor was 20.5 mg dm^{-3} (BRS-Zuri) and 14.40 mg dm^{-3} (*U. decumbens*). The resin extractor yielded the highest correlation indexes between PR and soil P content.

Keywords: Adsorption; Calibration; Extractors; Amazonian Soils.

Resumo

O objetivo deste estudo foi verificar e comparar a disponibilidade de P solos oxídicos cultivados com *Megathyrsus maximus* cv BRS-Zuri e *Urochloa decumbens* cv Basilisk e predizer o melhor extrator de P em pastagens no Sul da Amazônia. Dois experimentos foram conduzidos, o primeiro com gramínea BRS-Zuri e o outro com gramínea Braquiária. O delineamento experimental foi em blocos casualizados com cinco doses de P_2O_5 baseado na capacidade máxima de adsorção de P (CMAP), correspondendo com 0, 3, 6, 12 e 24% CMAP, com doses 0, 54, 108, 216 e 432 kg ha^{-1} de P_2O_5, com quatro repetições. Em cada corte das gramíneas foram determinados a massa seca, o acúmulo foliar de P gramíneas e análise do solo com Mehlich-1. A classe apropriada de P por Mehlich-1 foi 14,6 mg dm^{-3} (BRS-Zuri) e 7,2 (*U. decumbens*) mg dm^{-3}, pelo extrator de resina foi 20,5 mg dm^{-3} (BRS-Zuri) e 14,40 mg dm^{-3} (*U. decumbens*). O extrator de resina apresentou os maiores índices de correlação entre RP e teor de P do solo.

Palavras-chave: Adsorção; Calibração; Extratores; Solos Amazônicos.

Resumen
El objetivo de este estudio fue verificar y comparar la disponibilidad de P en un Oxisol cultivado con *Megathyrsus maximus* cv BRS-Zuri y *Urochloa decumbens* cv Basilisk y predecir el mejor extractor de P del suelo en pastizales de la Amazonía Sur. Se realizaron dos experimentos, uno con pasto BRS-Zuri y otro con pasto Signal. El diseño experimental fue bloques al azar con cinco dosis de P_2O_5 en base a la capacidad máxima de adsorción de P (MCAP), correspondientes a 0, 3, 6, 12 y 24% MCAP, con dosis de 0, 54, 108, 216 y 432 kg ha^{-1} de P_2O_5, con cuatro repeticiones. En cada corte de las gramíneas se determinó la masa seca, la acumulación de P foliar y mediante los extractores de resina y Mehlich-1 se verificó el P disponible. Hubo efectos de las dosis de P_2O_5 sobre las variables analizadas en ambas gramíneas. La clase apropiada de P por Mehlich-1 fue de 14.6 mg dm^{-3} (BRS-Zuri) y 7.2 (*U. decumbens*) mg dm^{-3}, por el extractor de resina fue de 20.5 mg dm^{-3} (BRS-Zuri) y 14.40 mg dm^{-3} (*U. decumbens*). El extractor de resina arrojó los índices de correlación más altos entre PR y el contenido de P del suelo.
Palabras clave: Adsorción; Calibración; Extractores; Suelos Amazónicos.

1. Introduction

The pastures are used as the primary source of feed for cattle in the Amazon region (Pinheiro et al. 2014). However, the main problems related to the establishment and maintenance of pastures in Brazilian Oxisols (Alves Filho et al. 2016), largely because these areas are partially or totally degraded (Dias-Filho, 2015) or due to improper practices (Guarda & Guarda, 2014), absence of fertilization or occurrence of sudden death syndrome *Uroclhoa brizantha* grass (Ribeiro-Junior et al. 2017).

One of the major problems is the extremely low levels of available phosphorus as well as the high adsorption capacity of Fe and Al oxides (Silva et al. 2016), and require very high P applications to increase production (Fonseca et al., 2020, Grohskopf et al., 2019, Teles et al., 2020). Another relevant factor that the phosphate fertilizers applied to the soils, observes the rates of use of P by the plants are reduced because the adsorption mechanisms (Guedes et al., 2016), mainly in highly weathered soils (Baldotto & Velloso, 2014).

The maximum P adsorption capacity (MPAC) can be used to assess the degree of interaction between P and the mineral matrix of the soil, which can be calculated by Langmuir adsorption isothermal (Filho et al., 2017), and the soil texture and mineralogy correlate with the adsorption of P (Corrêa et al. 2011). MACP and soil properties do solos interfere for P fertilization recommendations, it is worth noting that P is a non-renewable natural resource, phosphate fertilizers are costly and excessive application to the soil can cause environmental impacts (Alovisi et al., 2020). Therefore, the MACP in Amazonian soils is an important attribute and may complement the analyzes of fertility for pastures.

Thus, we consider a hypothesis for the study: (a) the methods of P availability in function of the maximum adsorption capacity of P do not differ in the cultived grasses in Southern Amazonia and (b) the resin method observes better correlation with productivity dry mass as extractor P of the soil in cultived grasses in Southern Amazonia. And the objective of this study was to verify and compare the P availability in an Oxisol cultivated with Megathyrsus maximus cv BRS-Zuri and *Urochloa decumbens* cv Basilisk and to predict the best soil P extractor in pastures in Southern Amazonia.

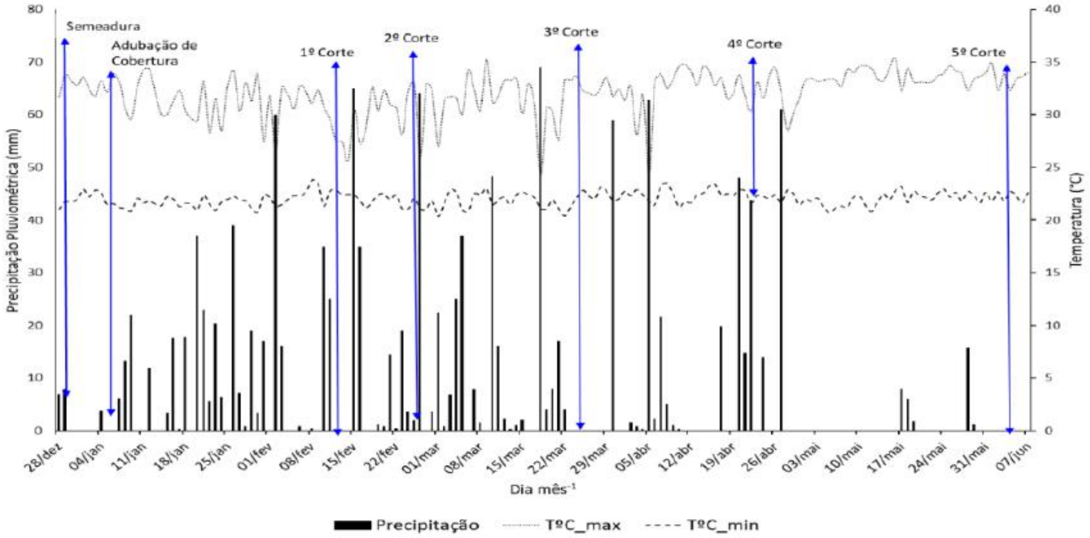
2. Methodology

Study area characterization

The research was carried out at the Leles farm (9 ° 27'41.46 "S and 56 ° 51'35.68" W) from October 2016 to July 2017, Southern Amazon. According to the Köppen classification, the climate of the region is tropical rainy with a dry season, mean annual rainfall of 2300 mm and mean temperature 28 ° C and a mean altitude of 320 m (Rodrigues et al. 2017).

The mean rainfall data were determined by the automatic stations provided by INMET (National Institute of Meteorology) (Figure 1).

Figure 1 - Weekly rainfall between December 2016 and May 2017, with sowing, cover fertilization and cuts of BRS-Zuri and Signal grasses on an Oxisoil, Southern Amazon.



Source: Authors (2022).

The conversion of the vegetation from Open Ombrophylous Forest to pasture occurred more than 15 years ago and the pasture has been established with Urochloa brizantha cv Marandu. The soil of the experimental area was classified as Oxisol (Hapludox) occurring in a flat relief (Soil Science Division Staff, 2017).

Table 1. Shows the soil used and the results of the chemical analysis and granulometric analysis of the 0-20 cm layer

Soil Properties	Oxisoil
Sand (g kg^{-1})	573
Silt (g kg^{-1})	32
Clay (g kg^{-1})	395
Bulk density (Mg m^{-3})	1.53
Organic Matter (g kg^{-1})	26.6
pH ($CaCl_2$)	4.4
$P_{Mehlich-1}$ (mg kg^{-1})	3.7
K($mmol_c$ kg^{-1})	2.5
Ca ($mmol_c$ kg^{-1})	12.4
Mg ($mmol_c$ kg^{-1})	5.6
Al ($mmol_c$ kg^{-1})	3.0
H+Al ($mmol_c$ kg^{-1})	39.6
CTC_{pH7} ($mmol_c$ kg^{-1})	57.0
B (mg kg^{-1})	0.18
Cu (mg kg^{-1})	0.80
Fe (mg kg^{-1})	97.0
Mn (mg kg^{-1})	18.3
Zn (mg kg^{-1})	1.40
Prem (mg L^{-1})[1]	30.50
MACP (mg g^{-1})[2]	0.391
AE (mg L^{-1})[3]	0.163

[1]Prem- remaining phosphorus, [2]MACP- Maximum adsorption capacity of phosphorus [3] Adsorption energy. Source: Authors (2022).

For the clay minerals of hematite (Hm), goethite (Gt), kaolinite (Ct) and gibbsite (Gb) was determined by the X-ray diffraction of iron oxides by boiling the clay fraction with NaOH (Norrish & Taylor, 1961) and by the powder method and deferrification of the clay fraction (Mehra & Jackson, 1960). The results of mean crystal diameter (MCD) were Gt110=16.64,

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Gt111=8.3, Hm110=8.57 e Hm012=50.66, width at half height (WHH) Ct=0.53 e Gb=0.26 $m^2\ g^{-1}$, specific surface area (SSA) Gt=178.19 e Hm=137.73 $m^2\ g^{-1}$, isomorphic substitution (IS) Gt=24.89 e Hm=16.52 mol%, HM/(Hm+Gt)=0.10, Ct/(CT+GB)=0.86, contents of Hm= 11.3 g kg^{-1} e Gt=52.5 g kg^{-1}.

Remaining P (Prem) was determined in 5 cm^3 air-dried fine soil (ADFS) samples for each soil class, using four replications. They were placed in 125 mL conical flasks, where 50 mL of a 0.01 mol L^{-1} $CaCl_2$ solution with 60 mg L^{-1} P were added. The solution was stirred for 5 min using a helical stirrer and allowed to stand for 16 h, following methodology of Alvarez and Fonseca (1990). Then, it was centrifuged for determination of the supernatant Prem concentration by the colorimetric method (Claessen, 1997).

The MACP was obtained from 2.5 g of soil, then added 0, 2, 4, 10, 20, 40, 60, 80, 100 e 120 mg mL^{-1} of P, diluted in CaCl2 0.01 mol L^{-1}, following methodology of Alvarez and Fonseca (1990) and with the Langmuir equation was possible to measure the maximum adsorption of P and adsorption energy in the soil.

For the construction of adsorption isotherms, used the P adsorbed plotted on the ordinate's axis and the predetermined contents in the equilibrium solution on the abscissa axis. The Langmuir equation in its hyperbolic form is expressed by:

$$x/m = (abC)/(1 + aC).$$

In order to estimate the constants a and b, the hyperbolic Langmuir equation was linearized: $C/(x/m) = 1/(ab) + (1/b)C$

where, x/m is the amount of P adsorbed by the soil, in mg P (x)/cm^3 of soil (m); b; soil MPAC, (mg cm^{-3} of P in soil); C: P contents in the equilibrium solution (supernatant) expressed in mg $L-1$; a: constant related to soil P binding energy (B.E.), expressed in L mg^{-1} (Olsen & Watanabe, 1957).

Experimental design

The experimental design was randomized blocks, with five doses of P_2O_5 based on the MACP established in the present study O, 3, 6, 12 e 24%, with dose of 0, 54, 108, 216 e 432 kg P_2O_5 ha^{-1}, in a Oxisoil, cultivated with Megathyrsus maximus cv. BRS-Zuri (experiment 1) and with *Urochloa decumbens* cv. Basilisk (experiment 2), with four replications. Each experimental unit was 5 m x 4 m, disregarding 1 m at each end for evaluation purposes.

Soil preparation and fertilization

In the experiment 1, was applied and incorporated 1.86 t ha^{-1} of dolomitic limestone with 37% CaO content and 12% MgO with total neutralizing reactive power (TNRP) of 85% and in the experiment 2 was applied 0.9 t ha^{-1} of dolomitic limestone.

Sowing was carried out under haul and with slight incorporation of seeds with the aid of rake and the application and incorporation of the granulated triple superphosphate was after 60 days of liming. The incorporation was with the aid of a rotary hoe at approximately 12 cm depth and, then, the sowing. For cover fertilization with N, 50 kg N ha^{-1} with a source of urea (45% - N) was used, with application to the haul without incorporation twenty days after sowing. There was application of 1 kg B ha^{-1} with source boric acid (17% - B), and 2 kg Zn ha^{-1} with source zinc oxide (50% - Zn), both applied at sowing, according to with Sousa and Lobato (2004).

Forage cutting and Analysis of soil and leaf contents

For the cutts of height of the forages were determined according to the rotational stocking method with variable stocking rate, with grazing height of 15 cm *Urochloa decumbens* cv. Basilisk (Bulegon et al., 2016) and it was 30 cm Megathyrsus maximus cv. BRS-Zuri (Euclides et al., 2016). In each experiment, five cuts were carried out using a cast metal square (0.5x0.5m) cast in the center of the plots, whenever the plots reached 50% of the grazing height.

Five soil samples were collected in each plot for each cut of the grass, with a Dutch type deal, at layer 0-10 and 10-20 cm depth. Subsequently dried in air, sieved and determined P in solution of Mehlich-1, with 0,05 mol L-1 HCl + 0,0125 mol L-1 H_2SO_4 (Mehlich 1978). After six sowings, the samples were collected in layers 0-10 and 10-20 cm deep, and the analyzes were performed by P-Mehlich-1 and anionic exchange resin (AER).

For the production of shoot dry mass (SDM) of the grasses was oven-dried at a mean temperature 65 ºC ± 2 ºC, for 72 hours. The samples after drying were ground and subjected to chemical analysis total P concentrations of leaves were determined via a standard Kjeldahl digestion (g kg^{-1}) using 3 mL of sulphuric acid (pure H_2SO_4) and 2 mL of hydrogen peroxide (H_2O_2, 30%).

The data were submitted to the normality test of the residues (Shapiro-Wilk> 5%) and homogeneity of the variances (Bartlett> 5%). For analyzes of variance (Ferreira 2015) by the F test (P <0.05) and for the regression analysis, we used the significant models and with higher determination coefficients (R^2).

The available P levels (mg dm^{-3}) in the soil were calculated as a function of the regression equations, in which the P content in the soil was correlated in each cut with a relative productivity of 80% (PR%). Data referring to the cut that presented the highest correlation coefficient (r).

3. Results and Discussion

There was a linear increase (P <0.05) of P_2O_5 in the accumulation of kg P ha^{-1} in all cuts of BRS-Zuri grass. There was also an effect (p <0.05) on all cuts of the Signal grass, however, with the doses of 414 kg ha-1 (1st cut), 273 kg ha-1 (2nd cut), 339 kg ha $^{-1}$ (3rd cut), 373 kg ha^{-1} (4th cut) and 410 kg ha-1 (5th cut) of P_2O_5 showed the highest accumulations of P in SDM (Table 2).

Table 2 - Regression equations for the effect of P_2O_5 doses on the accumulation kg P ha^{-1} by BRS-Zuri and Signal grasses, cultivated in an Oxisol and fertilized with P_2O_5 doses applied on the basis of MACP.

Variable	Equation	F	R²	¹MP
		BRS-Zuri grass		
1ºcut	y=7.93+0.0484x	55.47**	0.90	---
2ºcut	y=3.72+0.0159x	129.97**	0.88	---
3ºcut	y=4.06+0.0415x	331.21**	0.98	---
4ºcut	y=3.51+0.0163x	70.47**	0.96	---
5ºcut	y=4.42+0.0212x	169.62**	0.93	---
		Signal grass		
1ºcut	$y=2.10+0.0206x-0.000025x^2$	11.79**	0.83	414
2ºcut	$y=3.66+0.0114x-0.000021x^2$	10.32**	0.97	273
3ºcut	$y=4.83+0.0278x-0.000041x^2$	13.87**	0.94	339
4ºcut	$y=1.96+0.0261x-0.000035x^2$	12.69**	0.97	373
5ºcut	$y=4.01+0.0279x-0.000034x^2$	16.53**	0.99	410

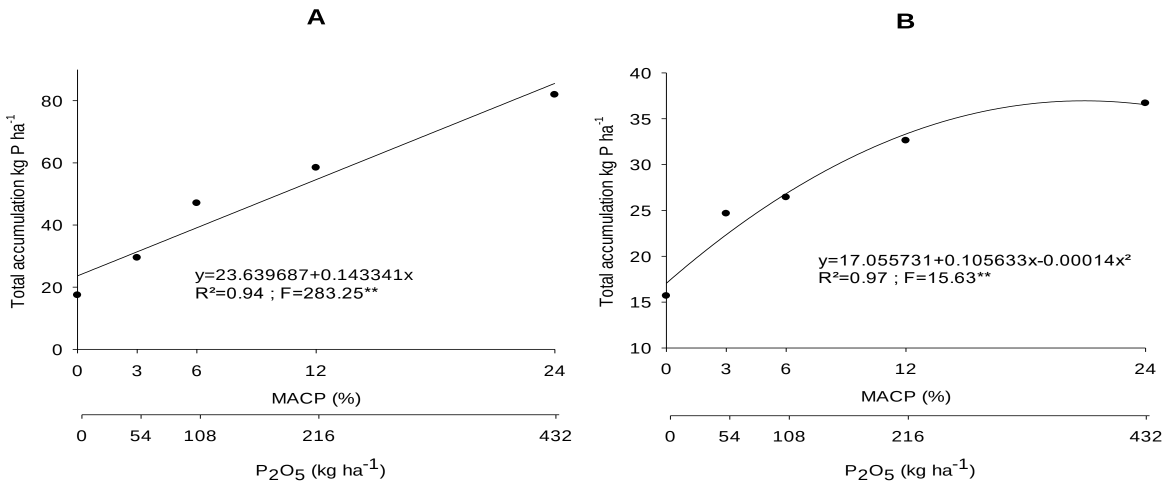
** significant at 1% probability. ¹ Maximum point (kg P_2O_2 ha^{-1}). Source: Authors (2022).

The doses of P2O5 significant effect (p<0.05) in total accumulation of kg P ha^{-1} in the SDM of both grasses. For the BRS-Zuri grass, there was a linear increase (Figure 2A) and for Signal grass the highest nutrient accumulation occurred with the application of 377 kg P_2O_5 ha^{-1} (Figure 2B).

The total accumulation of P by BRS-Zuri grass was 82 kg ha^{-1} of P, corresponding to 188 kg P_2O_5 ha^{-1}. While Signal grass had a total accumulation of 37 kg P ha^{-1}, equivalent to 85 kg P_2O_5 ha^{-1}. These results evidenced the higher requirement on

P by BRS-Zuri grass in relation to Signal grass, and this should be considered when picking the grass.

Figure 2 - Total accumulation kg P ha^{-1} in BRS-Zuri grass (A) and Signal grass (B), in an Oxisoil, in function of P_2O_5 doses applied based on MACP.



** significant at 1% probability Source: Authors (2022).

Increases in P accumulation by grasses caused by P_2O_5 doses in the form of triple superphosphate

There was an effect ($p < 0.05$) of the P_2O_5 doses on SDM production in all experiments and in all cuts, including the results of total dry mass production (Table 3). For BRS-Zuri grass, it was observed that with the doses of 292 kg ha^{-1} (1st cut), 363 kg ha^{-1} (2nd cut) and 338 kg ha^{-1} (3rd cut) P_2O_5, there were higher SDM, but in the 4th and 5th cuts the increases were linear (Table 3). For the Signal grass fodder, it was found that with the doses of 334 kg ha^{-1} (1st cut), 291 kg ha^{-1} (2nd cut), 429 kg ha^{-1} (3rd cut), 350 kg ha^{-1} cut) and 391 kg ha^{-1} (5th cut) of P_2O_5, there were larger increases in SDM production (Table 3).

Table 3 - Regression equations for the effect of P_2O_5 doses at SDM kg ha^{-1} by BRS-Zuri grass and Signal grass, cultivated in an Oxisol and fertilized with P_2O_5 applied on the basis of MACP.

Variable	Equation	F	R_2
	BRS-Zuri grass		
1ºcut	$y=1.720.37+29.8411x-0.051111x^2$	26.83**	0,97
2ºcut	$y=1.304.31+4.6481x-0.006409x^2$	9.08*	0,90
3ºcut	$y=1.657.91+26.3892x-0.039027x^2$	124.03**	0,99
4ºcut	$y=1.445.58+3.4811x$	38.03**	0,88
5ºcut	$y= 2.736.38+3.4534x$	40.49**	0,95
	Signal grass		
1ºcut	$y=822.51+6.0933x-0.009124x^2$	19.08**	0.71
2ºcut	$y=1,257.62+5.1601x-0.008886x^2$	168.10**	0.96
3ºcut	$y=2,087.99+10.4765x-0.012209x^2$	5.13**	0.90
4ºcut	$y=1,014.57+8.4471x-0.012089x^2$	13.00**	0.96
5ºcut	$y=2,163.34+9.1230x-0.011683x^2$	17.38**	0.98

* and ** significant at 5% and 1% probability. Source: Authors (2022).

With the dose of 341 kg P_2O_5 ha^{-1} and 19% da MACP, for the Zuri grass observed the greater production with 21.267 kg ha^{-1} of DM (Figure 3 A), and found 147% increase in relation to the absence of application. The Signal grass, with the dose

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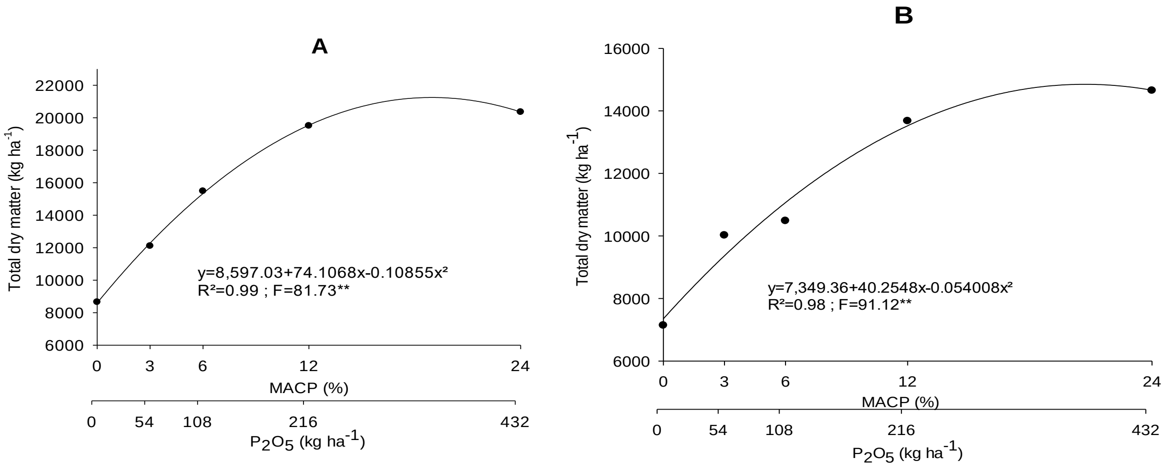
of 373 kg P_2O_5 ha^{-1} and 21% MACP, it increased dry mass accumulation with 13.493 kg ha^{-1} (Figure 3 B), there being 83,6% increase in relation to absence of phosphate fertilization.

A positive correlation (r<0.05) between available P (Mehlich-1) in the soil, in the layer de 0-10 cm, with the accumulation of P in the area and with the production of dry matter in both grasses in all cuts (Table 4). However, in the cuts of BRS-Zuri grass the correlation coefficient showed higher values than for Signal grass, confirming that the BRS-Zuri grass is more exaggerated and responsive to phosphate fertilization in relation to Signal grass.

Figure 3 – Total dry matter (kg ha^{-1}) de BRS-Zuri grass (A) e Signal grass (B), on an Oxisoil, in function of P_2O_5 doses applied based on MACP.



** significant at 1% probability. Source: Authors (2022).

Table 4 - Matrix of linear correlation (r) between soil phosphorus levels extracted by Mehlich-1 and anionic exchange resin extractors (soil layer 0-10 cm), with the accumulation of P and the production of dry matter of the BRS-Zuri grass and Signal grass in na Oxisoil.

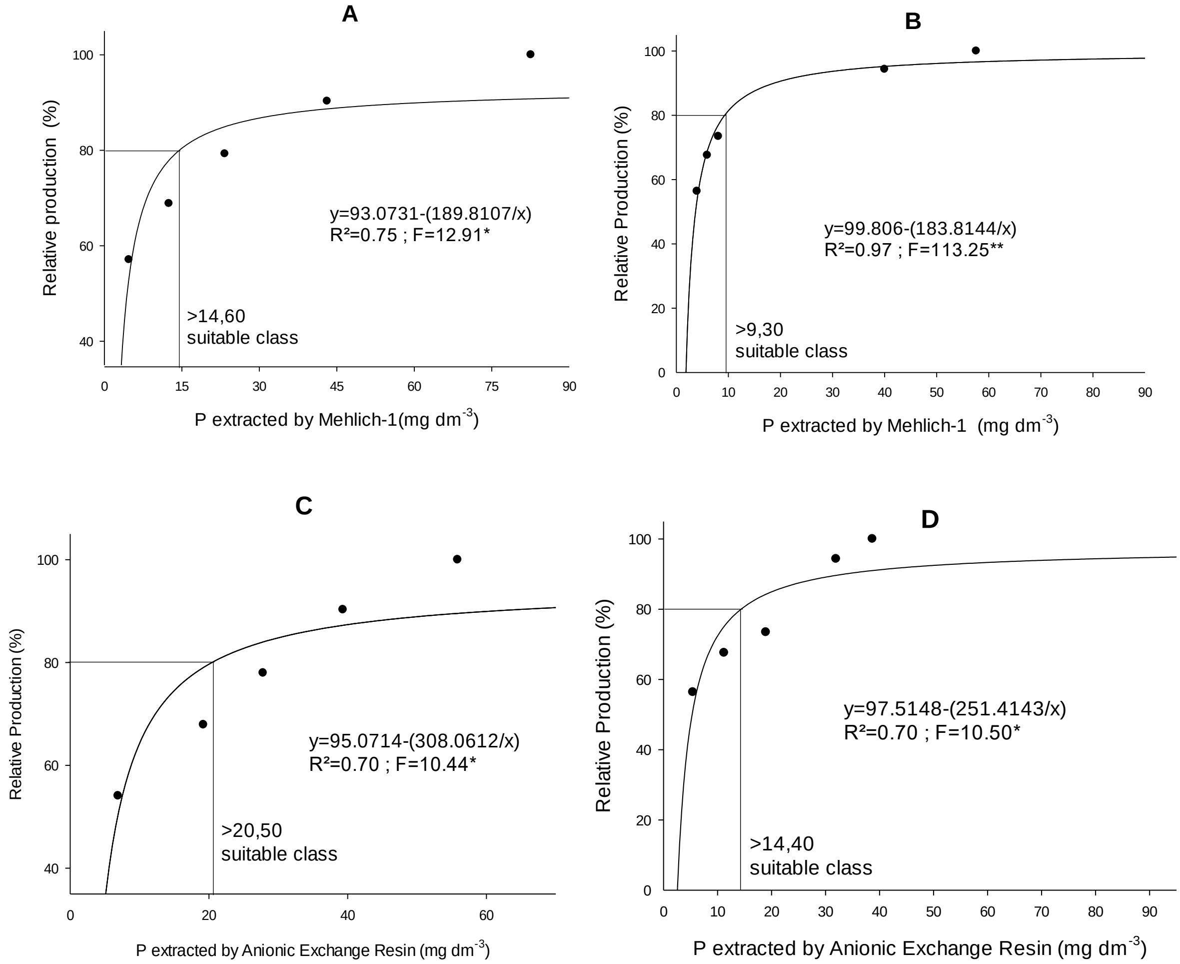
		Accumulation of P		Dry matter	
Extractors	Cuts	BRS-Zuri	Signal	BRS-Zuri	Signal
Mehlich-1	1º	0.82**	0.75**	0.79**	0.77**
	2º	0.90**	0.50*	0.79**	0.76**
	3º	0.96**	0.51*	0.86**	0.74**
	4º	0.92**	0.81**	0.86**	0.76**
	5º	0.94**	0.83**	0.87**	0.78**
Resin		Accumulation of P		Dry matter	
		BRS-Zuri			
	5º	0.97**		0.92**	
		Signal			
	5º	0.94**		0.91**	

* and ** significant at 5% and 1% probability. Source: Authors (2022).

It was observed that 5th cut there was a higher index of correlation (r=0,87) between relative production (RP 80 %) and e P extracted by Mehlich-1 for the BRS-Zuri grass (Figure 4 A) corresponding to an adequate P level of 14.6 mg dm^{-3}. For the Signal grass in the 5th cut it was observed a higher correlation index (r=0,78), with an appropriate P level of 9.3 mg dm^{-3} (Figure 4 B).

There was a higher correlation coefficient (r=0.92) in the 5th cut between 80% relative production and the P extracted by AER in the soil cultivated with the BRS-Zuri grass with a suitable P level of 20.5 mg dm^{-3} (Figure 4 C). For Signal grass, there was a higher correlation coefficient (r=0.91) and also in the 5th cut obseved the suitable P level of 14.4 mg dm^{-3} (Figure 4 D).

Figure 4 - Relative production of BRS-Zuri grass (A e C) and Signal grass (B e D) as a function of the P extracted by Mehlich-1 and anionic exchange resin (AER), in na Oxisoil, in the 0-10 cm layer, in the grasses collection in the 5th cut. Average of four replicates.



* and **: Significant at the probability level of 0.05 and 0.01. Source: Authors.

The effect of phosphate fertilization on the production of DM is due to the initial levels of P extracted by Mehlich-1 (3,7 mg dm^{-3}) and P-rem (30,50 mg L^{-1}), that according to Sousa and Lobato (2004) the content is low, the condition of high probability of response to fertilization. In addition, the high solubility of the source of P applied in the experiments that contribute to the increase of DM. These results confirm the importance of phosphate fertilization with high solubility, improving grass vigor in early development, providing pastures increased dry mass production.

The anionic exchange resin provided the highest values of linear correlation (P=0.05) in relation to Mehlich-1, both for the accumulation of phosphorus and for the production of dry matter (Table 4). The results of Oliveira et al. (2014) found that correlation values for the Mehlich-1 extractor were higher in relation to the resin extractor.

The lower current coefficients by the Mehlich-1 method are justified by the mineralogical characteristics of the Oxisols, with higher levels of goethite in relation to hematite. Raij et al. (2011) reported that the disadvantage in the use of Mehlich-1 extractor in soils where the labile phosphorus is mainly adsorbed in iron and aluminum oxides, preferring the extractors with greater action on the fraction, as is the case of the resin extractor. And also notes the long stirring and saturation time of the resin with the bicarbonate anion P adsorbed as colloidal surfaces for an electrochemical equilibrium between the soil and the soil resin surface contributions to higher values P for the analyzes in with relations Mehlich-1 (Mumbach et al., 2018).

It is possible to verify that there was an increase in the level of P by AER in relation to Mehlich-1. Souza et al. (2017) affirm that the AER it has no influence actor P capacity, because the available P values tend to be higher in comparison to Mehlich-1, the resin extractor pH of the solution does not change and the extraction process simulates the absorption of P by the roots of the plants.

4. Conclusion

The availability classes of P in an Oxisol cultivated with BRS-Zuri grass and Signal grass differed from the results found in the literature. Both phosphorus extractors studied can be used in samples of Oxisols of the Amazon region, however, the resin extractor presented higher correlation. But it is worth noting that the results are not valid for all types of Brazilian oxisols.

Acknowledgments

FAPEMAT e UNEMAT by the availability of scholarship assistance, in which it enabled the elaboration and execution of the project and the Laboratory of soil and foliar analysis - LASAF for the opportunity to perform soil and leaf analyzes in the present study.

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