PHOSPHORUS CRITICAL LEVELS AND AVAILABILITY IN LOWLAND SOILS CULTIVATED WITH FLOODED RICE

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ABSTRACT: Lowland soils present a great potential for the flooded rice crop. This work aimed to estimate critical levels of P in waterlogged soils cultivated with rice using Mehlich 1 and anion exchange resin as soil-P extractors, compare the performance of these extractors as for the evaluation of the P availability, and study the soil-P fractions involved in the P nutrition of the rice crop. Studied soils consisted of four Histosols: Low Humic Gley (GP), Aluvial (A), Humic Gley (GH) and Bog Soil (O) which were previously cultivated with beans. The experimental design was completely randomized, in a factorial scheme, using four soils, five P rates (75, 150, 300, 500 and 800 mg dm^{-3}) and two liming treatments (with and without liming), with three replicates. After 60 days of flooding, soil samples were submitted to P extraction by Mehlich 1 and resin, and phosphorous fractionation. Two rice plants were cultivated in pots containing 3 dm^3 of waterlogged soils. The labile P and the moderately labile P of the soils contributed for rice nutrition. The two tested extractors presented efficiency in the evaluation of P availability for the rice cultivated in lowland waterlogged soils.
Key words: *Oryza sativa*, phosphorus fractions, extractors

NÍVEIS CRÍTICOS E DISPONIBILIDADE DE FÓSFORO EM SOLOS CULTIVADOS COM ARROZ INUNDADO

RESUMO: Os solos de várzea apresentam-se com um grande potencial para o cultivo do arroz irrigado por inundação. No presente trabalho, objetivou-se estimar os níveis críticos de P pelos extratores Mehlich 1 e resina em solos de várzea cultivados com arroz sob inundação e identificar as frações de P que estão contribuindo para a nutrição fosfatada do arroz. Foram utilizados quatro solos de várzea pré-cultivados com feijoeiro: Glei Pouco Húmico (GP), Aluvial (A), Glei Húmico (GH) e Orgânico (O). O experimento foi em delineamento inteiramente casualizado, em fatorial 4 x 5 x 2 com três repetições, sendo: quatro solos, cinco doses de P (75, 150, 300, 500 e 800 mg dm^{-3}) e dois níveis de calagem: ausência e presença. Após 60 dias de inundação, coletaram-se amostras dos solos para a determinação do P por Mehlich 1 e resina e fracionamento de P. Cada parcela constituiu de um vaso de 3 dm^3 em que cultivaram-se duas plantas. As formas de P lábeis e pouco lábeis dos solos contribuíram para a nutrição fosfatada do arroz. Os dois extratores demonstraram eficiência na avaliação do P disponível para o arroz.
Palavras-chave: *Oryza sativa*, fração de fósforo, extratores

INTRODUCTION

Soil chemical analysis is the principal tool for soil fertility evaluation. The dose of fertilizer to be applied to the soil is mainly based on the diagnosis of the nutrient availability in the soil. A recent literature review has reported that phosphorous (P) availability prediction has been extensively studied over the last decades (Silva & Raij, 1999). However, it is not well known yet how methods are the most suitable for the evaluation of phosphorous availability in waterlogged soils.

Evaluation methods of P availability for rice in drained soils have been tested for flooded rice in lowland soils. Among them, Mehlich 1 is the most available method for Minas Gerais State even if anion exchange resin (resin) is considered more promising in evaluating P availability in flooded rice fields (Grande et al., 1986; Motta et al., 1994).

According to Motta et al. (1994) the P extraction from waterlogged soils by resin was less influenced by variations in organic matter contents and soil texture than by acid extractors. Grande et al. (1986) verified a high correlation between P taken up by flooded rice plants and amount of the nutrient extracted by resin, and a good correlation between Melhich 1 and P uptake by plants only in soils with less than 10% of organic matter.

Although waterlogged lowlands exploitation with agricultural activities endanger the ecosystem, there are not many information about amounts of P to be applied seeking to avoid environmental impacts. P dynamics in these soils are ever far too complex, because reactions of reduction and hydrolysis of other compounds (oxides and hydroxides) affect P contents in soil solution (Lindsay, 1979). Hence, P dynamics in flooded soils can be well described by approaching forms of P in soils using method of fractionation (Hedley et al., 1982). The P fractions of soils related to available P by extractors, would allow the identification of the most extractable pool of P for each soil, and then, the selection of the most efficient method for a particular area (Barbosa Filho et al., 1987). Obviously, the P amounts obtained by extraction should be correlated to growth and total P taken up by plants.

The objective of this work was to estimate critical levels of P in four waterlogged soils cultivated with rice by extractors Melhich 1 and resin, compare the performance of these extractors as for the evaluation of the P availability, and to find out which organic and inorganic forms of soil phosphorous contribute most to P nutrition of rice in these systems.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse at the Department of Soil Science at the Federal University of Lavras, using pots containing 3 dm^3 of each soil sample studied. Flooded rice plants (*Oriza sativa* L. cv. Jequitibá) were cultivated during the period October 1998- February 1999, in samples (0-20 cm) of four Histosols previously treated with 5 P doses (Fernades et al., 2000) and with 2 liming levels (Faquin et al., 1998) and cultivated with beans plants.

Chemical, physical and mineralogical attributes of the natural samples of these soils are presented in Table 1.

The experiment with bean was carried out in 3 dm^{-3} pots, greenhouse conditions. Pots were seeded with three plants, and one plant was harvested at the flowering period and the other two at the end of the cycle. Trials were set up in a completely randomized design. Treatments included all possible combinations among 4x5x2 factorial four soils, five P doses and 2 liming levels –liming and no liming (n=4). The Bog Soil (O) sample was artificially drained, showing lower rates of organic matter. Lime was applied to raise soil base saturation to 70%, and consisted of a CaO (35%) + MgO (14%) mixture, as recommended by Faquin et al. (1998).

Upon harvesting the bean plants, soils were air dried, passed through a 5 mm sieve, sampled, for chemical analysis and planted with flooded rice. Except for the number of replicates (3), trials were set up as described for the bean crop assay. Before flooding and sowing, soils were thoroughly mixed with macro and

Table 1 - Chemical, physical and mineralogical attributes of Low Humic Gley (GP), Aluvial (A), Humic Gley (GH), and Bog Soil (O).

Soil	pH[1]	P[1]	K[1]	Ca[1]	Mg[1]	Al[1]	H+Al[1]	t[1]	T[1]	m[1]	V[1]	PAMC[2]	PR[2]
		mg dm^{-3}		cmol$_c$ dm^{-3}						-- % --		mg kg^{-1}	mg L^{-1}
GP	4.5	3	36	0.6	0.2	1.1	6.3	2.0	7.2	55	12	648	28
A	4.7	3	103	2.7	1.1	0.2	4.5	4.3	8.6	5	47	689	27
GH	4.7	8	51	0.7	0.2	1.6	13.7	2.6	14.7	61	7	2404	1.77
O	4.6	6	76	1.6	1.2	0.9	9.8	3.9	12.8	23	23	1051	16

Soil	Coarse Sand	Fine Sand	Silt	Clay	Organic Matter	Bulk Density	Density of particles	Specific surface area
	g kg^{-1}					g cm^{-3}		m^2 g^{-1}
GP	30	611	179	180	31	1.0	2.7	121
A	0	179	471	350	31	0.8	2.8	137
GH	10	230	390	370	230	0.4	1.8	335
O	0	120	570	310	44	0.6	2.1	181

Soil	SiO$_2$[3]	Al$_2$O$_3$[3]	Fe$_2$O$_3$[3]	TiO$_2$[3]	P$_2$O$_5$[3]	Fed[4]	Feo[4]	Feo/Fe$_d$[5]	Gb[4]	Ct[4]
	g kg^{-1}									
GP	84.2	112.2	13.0	6.2	0.1	1.8	0.6	0.33	19	65
A	209.3	221.1	74.5	9.3	0.5	12.3	0.5	0.04	49	143
GH	126.1	175.5	13.3	5.5	1.5	2.3	0.6	0.26	53	48
O	243.4	247.1	42.8	7.3	0.5	5.3	0.5	0.09	57	121

[1] pH = pH in water; P = phosphorous by Mehlich 1; K = potassium; Ca = calcium; Mg = magnesium; Al = changeable aluminum; H+Al =changeable acidity; t = cationic exchange capacity at natural pH; T = cationic exchange capacity at pH 7.0; m = Al saturation ; V = soil base saturation; physical attributes from EMBRAPA (1997)

[2] PR = P remaining e PAMC= P-adsorption maximum capacity (Alvarez V. and Fonseca, 1990)

[3] Sulfuric-extracted oxides (EMBRAPA, 1997);

[4] Fe$_d$ = Fe dithionite extractable; Fe$_o$ = Fe oxalate extractable; Ct = kaolinite; Gb = gibbsite (Mehra & Jackson, 1960)

[5] Fe$_o$/Fe$_d$ = Fe oxides' activity (Kämpf, 1988)

micronutrients: 70 mg N dm^{-3} as NH_4NO_3, 100 mg K dm^{-3} as KNO_3, 50 mg S dm^{-3} as $(NH_4)_2SO_4$, 0.5 mg B dm^{-3} as H_3BO_3, 0.75 mg Cu dm^{-3} as $CuSO_4.5H_2O$, and 2.5 Zn N dm^{-3} $ZnSO_4.7H_2O$ (p.a. forms).

Soils were flooded for 60 days (3 cm of water or the soil surface). Soil portions were then sampled 3 cm below the soil surface and evaluated through Mehlich 1 (EMBRAPA, 1997) and resin (Raij, et al., 1987) methods; chemical fractionation was done as proposed by Ivanoff et al. (1998) for Histosols: a sequential extraction of labile forms following the moderately labile and non-labile forms, but the moderately labile P_o (fulvic acids) was not separated from the non-labile P_o pool (humic acids) in the NaOH extract, as suggested by the authors.

Two 0.5-g samples of dry soil were taken from each pot for P fractionation. In one of the samples, P associated with the soil live microbial biomass was estimated through chloroform ($CHCl_3$) fumigation (Hedley and Stewart, 1982). Total, labile P (P_i-$NaHCO_3$ + P_o microbial) was determined according to Pavan & Chaves (1996). The remaining soil was used for determination of succeeding fractions. On the other sample, only the extraction with 30 mL of $NaHCO_3$ (0.5 mol L^{-1}) was applied after the determination of inorganic labile P (P_i-$NaHCO_3$) in the extracts. The difference between the amounts of P-$NaHCO_3$ in the $CHCl_3$-treated and untreated samples represents the P_o microbial, a significant portion of the readily bioavailable pool of P.

The organic and inorganic forms of NaOH-extractable P were determined by adding 30 mL of NaOH (0.5 mol L^{-1}) to the samples. Tubes were shaken for 16 hours and the P_i-NaOH was obtained in the extract. The extract was then autoclaved and P-NaOH (P_i-NaOH + P_o-NaOH) was determined the amount of P_o-NaOH was calculated as the difference between P-NaOH and P_i-NaOH. The remaining soil was used on the subsequent extraction.

The determination of P_i-HCl was done using 30 mL of HCl (1 mol L^{-1}). Samples were centrifuged at 7000 rpm for 15 minutes and P was determined on the solution surface. The remaining soil was digested with H_2SO_4 (0.5 mol L^{-1}) and H_2O_2 to determine P-residual. The colorimetric method described by Murphy & Rilley (1962) was used to determine P in all extracts.

After fractionation, P-forms were defined as: Labile P (LP) = P_i-$NaHCO_3$ + P_o microbial; Moderately labile P (MLP) = P_i-HCl + P_i-NaOH + P_o-NaOH; Non-labile P (NLP) = P-residual; and Total P (TP) = LP + MLP + NLP.

During the cultivation period, N and K were applied according to the species requirements. Treatments in which rice plants showed satisfactory development in each growth stage received 500 mg N dm^{-3} and 500 mg K dm^{-3}, split in 8 applications. Proportional doses were applied to the rest of the treatments, according to the growth of the plants.

At the end of the cycle, rice plants were harvested, oven-dried at 65-70°C and weighed. The dried shoot was ground to pass a 0.5-mm sieve and P was extracted as recommended by Malavolta et al. (1997). Grains were harvested, oven dried at 40-45°C until 13% moisture, cleaned, peeled and weighed. Phosphorus concentration in shoots, total P taken up by plants and grain yield were measured.

Data were submitted to ANOVA and regression analysis. Regression equations were adjusted to the average grain yields as a function of P rates utilized, and from these equations, the ins' physiological ripening and P extracted from soils by the two extractors.

Correlation between P-fractions in soils and P taken up by plants were estimated in order to identify the relationships between fractions of P in the soils and P nutrition of rice plants. Correlation between P-fractions in soils and P extracted by extractors Mehlich 1 and resin was calculated.

RESULTS AND DISCUSSION

Phosphorus fractions in soils and phosphorus nutrition of rice

Significant correlation was observed between P_i-$NaHCO_3$, P_o-microbial and total labile P with the total P taken up by rice plants in soils with and without liming (Table 2). Both forms – P_o-microbial (Brooke et al., 1984) and P_i-$NaHCO_3$ (Bownan & Cole, 1978; Tiessen et al., 1992) – are considered the main pools of available P to plants.

In general, the fractions P_o-NaOH, P_i-NaOH, P_i-HCl, total moderately labile P, and P-total showed significant correlation with total plant P, independently of liming rates (Table 2). The fractions P_o-NaOH and total moderately labile P were not significantly correlated to the total plant P only in the limed GH soil conditions.

Ivanoff et al. (1998) suggested that humic acids represent the non-labile P pool in soils while fulvic acids comprise the moderately labile P_o sources, which can become available to plants. Liming probably interfered in the distribution of organic (moderately labile) P pools in the GH soil.

All fractions of moderately labile P were significantly correlated to P taken up by plants on non-limed GH soil. Phosphorus fractions connected to amorphous or crystalline phosphates of Fe and Al which are considered of low availability to plants (Willians et al., 1980) can be NaOH-extracted. The P_i-HCl is referred to the calcium phosphates (Walker & Syers, 1976) made available in the long run through weathering in unfertilized soils of temperate regions (Smeck, 1985). However, in tropical acid, drained soils, this form of P resulting from liming, is less stable than P bound with Fe or Al, and readily available to plants (Araújo et al., 1993). In reduced systems, Fe and Al phosphates are hydrolyzed by chelatants formed from anaerobic

Table 2 - Pearson's correlation coefficients between total P taken up by plants and P forms in Low Humic Gley (GP), Aluvial (A), Humic Gley (GH) and Bog Soil (O) soils.

	Soils				
P forms	GH	GP	O	A	All grouped
		With liming			
P_o-microbial	0.96**	0.82*	0.99**	0.98**	0.96**
P_i-$NaHCO_3$	0.92**	0.86*	0.85*	0.97**	0.95**
labile P-total	0.95**	0.87*	0.98**	0.98**	0.97**
P_o-NaOH	- 0.21ns	0.85*	0.94**	0.89*	0.87*
P_i-NaOH	0.89*	0.91*	0.90*	0.89*	0.90*
P_i-HCl	0.91*	0.86*	0.92*	0.91*	0.91*
Moderately labile P- total	0.09ns	0.93**	0.94**	0.90*	0.87*
P-residual	0.95**	0.97**	0.99**	0.99**	0.98**
P- total	0.87*	0.92**	0.98**	0.97**	0.96**
		Without liming			
P_o-microbial	0.97**	0.93**	0.80*	0.99**	0.96**
P_i-$NaHCO_3$	0.93*	0.97**	0.86*	0.99**	0.97**
labile P-total	0.95**	0.98**	0.89*	0.99**	0.98**
P_o-NaOH	0.94**	0.84*	0.84*	0.98**	0.95**
P_i-NaOH	0.94**	0.97**	0.80*	0.94**	0.96**
P_i-HCl	0.99**	0.80*	0.92*	0.90*	0.88*
Moderately labile P- total	0.96**	0.96**	0.81*	0.97**	0.97**
P-residual	0.99**	0.95**	0.99**	0.97**	0.98**
P- total	0.98**	0.98**	0.86*	0.99**	0.98**

**significant at the 0.05 probability level; *significant at the 0.01 probability level; ns - non-significant.

decomposition of organic matter, and P is released to the soil solution becoming available to the plants (Ponnamperuma, 1972). Subsequently, flooding breaks down calcium phosphate (Ponnamperuma, 1972) and increases P diffusion in soils (Turner & Gilliam, 1976). This is probably how moderately labile P (Ivannof et al., 1998) is made available to plants after flooding, enhancing P supply to them.

Although the correlation between moderately labile P forms and total P taken up by plants was significant, there was no evidence that moderately labile P was taken up by plants. Furthermore, the lag period between P fertilization and rice cultivation may have not been long enough to establish this form in the soils.

The residual P-fraction represents the non-labile P bound up with minerals structurally free from P – hematite, goethite, and gibbsite (Smeck, 1985). Phosphorus application leads to an increase on retention of P in the soil by those minerals, contributing each time more to its occlusion. Concurrently, plants absorb more P, and that might justify the high correlation observed between P taken up by plants and the residual P form on soils.

Critical levels of P in soils

Regression equations were adjusted for values of P extracted by Mehlich1 and resin extractors and the P rates applied to each soil for each liming level (Table 3). Critical levels of P were estimated by Mehlich 1 and resin (Table 5) by substituting the P rates respective to 90% of the maximum grain yield (Table 4) in these equations. The critical levels of P evaluated with resin decreased as follows: GP>GH>A>O without liming, and GP>A>GH ≅ O with liming. Working with 9 flooded soils, Mello (1991) reported a wide variation among critical levels of P, also depending on the type of extractor utilized to assess the P status in the soils.

Independently of extractor and liming level, the highest values of P critical levels were found for GP. These values are probably a consequence of the low phosphate buffering capacity observed for a large amount of PR and low values of PAMC in this soil (Table 1). In addition, GP soil has high P-adsorption capacity in solution in reduced systems which is, confirmed by the high ratio Fe_o/Fe_d (Table 1). Since this soil shows a low phosphate buffering capacity and a fast exhaustion of P in solution, high concentrations of available P is expected to be maintained in soil solution.

The literature shows that the P availability to rice plants is related to the P buffering capacity of soils (Hossner et al., 1973; Sanchez & Smith, 1980; Moraes & Dynia, 1992). Significant correlations between P critical levels by resin and P remaining (PR) in limed soils were verified (Table 6), characterizing their P buffering capacity (Muniz et al., 1985).

Mello (1991) observed that critical soil levels of P extracted by Mehlich 1 are not highly correlated to soil attributes that express phosphate-buffering capacity, but this correlation is higher when anionic paper, which behaves similaCrly to the anion exchange resin, is used as extractor. According to Mello (1991), the extractor Mehlich 1 destroys part of the adsorption matrix – the low stability oxides. Nevertheless, these oxides remain intact during P adsorption analysis (*i.e.* P remainder or any other measure of P buffering capacity). The amount of P extracted by Mehlich 1 can differ among soils with equal buffering capacity but with different oxides stability. In fact, soils A and GP, that showed different critical values of P established by Mehlich 1 (Table 5), were similar in their P buffering capacity, but differed regarding their stability of oxides (Table 1).

Table 3 - Regression equations of P-available by extractors (Y = mg dm^{-3}), as dependent variable of P rates applied (X = mg dm^{-3}) in the soils. Low Humic Gley (GP), Aluvial (A), Humic Gley (GH) and Bog Soil (O).

Soil	Extractor	Equation	R^2
		With liming	
GH	Mehlich 1	$Y = 18.1382 + 0.2291^{**} X$	0.96
	Resin	$Y = 27.9765 + 0.1360^{*} X$	0.87
GP	Mehlich 1	$Y = 4.8315 + 0.3358^{**} X$	0.99
	Resin	$Y = 42.0047 + 0.3496^{**} X$	0.97
O	Mehlich 1	$Y = 15.6334 + 0.2196^{**} X$	0.99
	Resin	$Y = 11.6535 + 0.1725^{**} X$	0.94
A	Mehlich 1	$Y = - 8.1765 + 0.1627^{**} X$	0.99
	Resin	$Y = - 1.4371 + 0.3190^{**} X$	0.99
		Without liming	
GH	Mehlich 1	$Y = 9.5811 + 0.2943^{**} X$	0.98
	Resin	$Y = 35.209 + 0.1756^{**} X$	0.99
GP	Mehlich 1	$Y = 35.3728 + 0.2960^{**} X$	0.96
	Resin	$Y = 78.0121 + 0.1397^{*} X$	0.84
O	Mehlich 1	$Y = 0.5822 + 0.2088^{**} X$	0.99
	Resin	$Y = 13.520 + 0.1843^{*} X$	0.99
A	Mehlich 1	$Y = 1.2580 + 0.0123^{**} X$	0.99
	Resin	$Y = 9.1571 + 0.1475^{**} X$	0.96

** significant at 0.01 probability level by t-test.

Table 4 - Maximum grain yield and 90% of the maximum production and P rates to reach these productions in the soils Low Humic Gley (GP), Aluvial (A), Humic Gley (GH) and Bog Soil (O).

	GrainYield		P rates	
Soil	90%	Maximum	90%	Maximum
	---------- g pot^{-1} ----------		---------- mg dm^{-3} --------	
		With liming		
GH	63.3	70.4	373	612
GP	79.6	88.5	342	519
O	86.0	95.5	390	609
A	81.8	90.9	378	571
		Without liming		
GH	50.8	56.4	361	634
GP	45.6	50.7	336	623
O	55.9	62.1	281	489
A	86.6	96.3	398	622

Except for the critical levels estimated by resin in treatments with liming (Table 7), positive, significant correlations between P critical levels and oxide activity (Fe_o/Fe_d) were observed. Lime stabilizes Fe oxides in flooded systems (Mello, 1991) and increases the capacity of the soil to supply P to plants (Silva & Raij, 1999). The high correlation between critical levels of P extracted by resin in limed soils with P buffering capacity (Table 6) supports the idea that the resin method identified these effects more effectively.

Resin is the only P extraction method that reveals adequately the liming effect on increasing P availability to plants (Silva & Raij, 1999). In general, the critical levels of P in the treatments with and without liming were dependent on the Fe oxide activity when estimated with Mehlich 1 and also on the Fe oxide activity and P remaining when measured by resin.

P availability by extractors Mehlich 1 and resin

The liming x soil x P rate interaction altered ($P<0.01$) the P status evaluated by Mehlich 1 and resin. In general, the P concentrations available by extractors decreased as follows: GP>GH>O>A, except for resin in limed soils, which showed a decrease in P concentrations available by extractors as follows: GP>A>GH>O.

Table 5 - Estimated P critical levels in waterlogged soils to flooded rice, correspondent to 90% of the maximum production by extractors resin and Mehlich 1, in soils Low Humic Gley (GP), Aluvial (A), Humic Gley (GH) and Bog Soil (O).

	Extractors			
	With liming		Without liming	
Soil	Mehlich 1	Resin	Mehlich 1	Resin
	---------------------- mg dm^{-3} ----------------------			
GH	103.75	78.77	115.95	98.76
GP	119.81	161.71	134.76	124.93
O	101.30	78.95	59.17	65.23
A	53.35	119.21	50.22	67.82

Table 6 - Pearson's correlation coefficients between P critical levels and P-remaining and Fe oxide activity (Fe_o/Fe_d) in the studied waterlogged soils.

Extractor		Mehlich 1	resin
With liming	P-remainder	0.18 ns	0.99**
	Fe oxides' activity	0.83**	0.44ns
Without liming	P-remainder	0.47ns	0.67ns
	Fe oxides' activity	0.99**	0.97**

**significant at the 0.05 probability level; *significant at the 0.01 probability level; ns - non-significant.

Table 7 - Pearson's correlation coefficients between available P by extractors and forms of P in the studied waterlogged soils.

P forms	Extractors	Soils				
		GH	GP	O	A	All grouped
		With liming				
P_o-microbial	Mehlich 1	0.98**	0.92**	0.90*	0.98**	0.96**
	Resin	0.88*	0.81*	0.78ns	0.98**	0.93**
P_i-NaHCO$_3$	Mehlich 1	0.93**	0.93**	0.98**	0.98**	0.97**
	Resin	0.97**	0.90*	0.99*	0.99**	0.97**
Labile P- total	Mehlich 1	0.96**	0.95**	0.99**	0.98**	0.98**
	Resin	0.97**	0.90*	0.94**	0.99**	0.97**
P_o-NaOH	Mehlich 1	-0.21ns	0.94**	0.97**	0.90*	0.92**
	Resin	-0.14ns	0.87*	0.97**	0.91*	0.92**
P_i-NaOH	Mehlich 1	0.93**	0.91**	0.93**	0.92*	0.93**
	Resin	0.83*	0.86*	0.85*	0.92**	0.91**
P_i-HCl	Mehlich 1	0.93**	0.94**	0.96**	0.91*	0.95**
	Resina	0.74ns	0.88*	0.88*	0.91*	0.89*
Moderately labile P- total	Mehlich 1	0.17ns	0.97**	0.97**	0.91*	0.92**
	Resin	0.54ns	0.91*	0.88*	0.91*	0.91**
P-residual	Mehlich 1	0.96**	0.99**	0.99**	0.99**	0.99*
	Resin	0.80*	0.98**	0.98**	0.99**	0.97**
P-total	Mehlich 1	0.91*	0.98**	0.99**	0.97**	0.98*
	Resin	0.96**	0.93**	0.94**	0.98**	0.97**
		Without liming				
P_o-microbial	Mehlich 1	0.95**	0.83*	0.87*	0.99**	0.93**
	Resin	0.98**	0.97**	0.81*	0.97**	0.98**
P_i-NaHCO^3	Mehlich 1	0.93**	0.96**	0.97**	0.99**	0.98**
	Resin	0.93**	0.84*	0.98**	0.98**	0.97**
Labile P- total	Mehlich 1	0.97**	0.94**	0.96**	0.99**	0.99**
	Resin	0.96**	0.94**	0.98**	0.98**	0.98**
P_o-NaOH	Mehlich 1	0.96**	0.66ns	0.99**	0.94**	0.93**
	Resin	0.93**	0.96**	0.99**	0.94**	0.97*
P_i-NaOH	Mehlich 1	0.94**	0.83*	0.98**	0.91*	0.97*
	Resin	0.95**	0.90*	0.97**	0.87*	0.95*
P_i-HCl	Mehlich 1	0.97**	0.90**	0.96**	0.82*	0.97**
	Resin	0.99**	0.75ns	0.98**	0.84*	0.94**
Moderately labile P- total	Mehlich 1	0.96**	0.83*	0.99**	0.92**	0.97**
	Resin	0.96**	0.83*	0.98**	0.92*	0.97**
P-residual	Mehlich 1	0.98**	0.90*	0.99**	0.99**	0.99**
	Resin	0.99**	0.90**	0.99**	0.97**	0.98**
P-total	Mehlich 1	0.97**	0.92**	0.98**	0.98**	0.99**
	Resin	0.99**	0.92**	0.98**	0.97**	0.98**

**significant at the 0.05 probability level ; *significant at the 0.01 probability level; ns - non-significant.

Except for GH soil with and without lime, and O soil with lime, resin extracted more P than Mehlich 1. The GH soil contained high amounts of organic matter and total P, suggesting a contribution of organic P to the values found with the acid extractor. Mehlich 1 can extract relatively high amounts of P in soils with high organic matter contents (>10%), with P_o forms, not available to plants, apparently included (Grande et al., 1986). However, the high correlation between P_o microbial (labile) and P extracted by Mehlich 1 as well as the very low correlation between Mehlich 1 and P_o-NaOH (moderately labile) suggest that Melhich 1 extracted only available organic forms of P off the GH soil. The P_o-NaOH fraction did not show correlation with P extracted by either Mehlich 1 or resin, as did the total moderately labile P (Table 7).

P_o microbial is one of the most important P forms in plant nutrition (Brooke et al., 1984) showing the highest correlation with total P taken up by plants (Table 2). In the limed O soil, P extracted by resin was not correlated with this form, meaning that the principle of the resin method (the transference of labile P from soil to resin by anionic exchange) showed efficiency only for the labile inorganic P form of limed O soil, as confirmed by the high correlation between P extracted and P_i-$NaHCO_3$ (Table 7).

Both extractors were similar in their ability to extract P fractions from all soil groups (Table 7). Research has demonstrated that Mehlich 1 has been somewhat inefficient in predicting P availability to flooded rice in lowland soils (Grande et al., 1986), probably because there is a predominance of P-Fe in these soils (Mahapatra & Patrick, 1969), and acid extractors extract preferentially P-Ca (Raij, 1991). However, researchers who studied the relationship between available and inorganic P fractions, have reported that Mehlich 1 predominantly extracted P from P-Fe in Latosols, recommending the use of this extractor for soils with predominance of P-Fe (Barbosa Filho et al., 1987).

Phosphorus extracted either by resin or by Mehlich 1 had positive correlation with total P taken up by plants for each soil and for all, grouped, limed or non-limed soils (Table 8). Considering the relations between P extracted by Mehlich 1 and resin with labile P (Table 7), and total P taken up in shoot (Table 8), it can be concluded that both Mehlich 1 and resin methods were efficient in the evaluation of P availability to flooded rice in the soils studied.

Grande et al. (1986) referred to resin as an effective and to Mehlich 1 as a non-effective method for prediction of availability of P to flooded rice. The authors consider that clay contents, organic matter, and total P discreetly influence resin extraction, suggesting that resin detects almost all labile P availability to rice in waterlogged soils. Motta et al. (1994) also reported resin as not only the most efficient method to evaluate P availability to plants in lowland, waterlogged soils, but also a method that is less influenced by variations in organic matter content and soil texture than acid extractors.

Table 8 - Pearson's correlation coefficients between available P by extractors and P taken up in shoot in the waterlogged soils studied.

	Extractors			
	With liming		Mehlich 1	
Soils	Mehlich 1	Resin	Mehlich 1	Resin
GH	0.99**	0.83*	0.98**	0.99**
GP	0.97**	0.99**	0.92**	0.93**
O	0.99**	0.99**	0.81*	0.88*
A	0.98**	0.98**	0.98**	0.98**
All grouped	0.99**	0.98**	0.94**	0.99**

**significant at the 0.05 probability level; *significant at the 0.01 probability level; ns - non-significant.

CONCLUSIONS

Both labile P forms and moderately labile P forms may be contributing to the P nutrition of rice in the studied Histosols. The critical levels of P estimated by Melhich 1 were: 104 (mg P dm^{-3}) (GH), 120 (mg P dm^{-3}) (GP), 101 (mg P dm^{-3}) (O), and 53 (mg P dm^{-3}) (A), with liming; and 116 (GH), 135 (GP), 59 (O), and 50 (A) without liming. When estimated by resin, critical levels of P were (mg P dm^{-3}): 79 (GH), 162 (GP), 79 (O) and 119 (A) with liming; and 99 (GH), 125 (GP), 65 (O), and 68 (A) without liming. Mehlich 1 and resin extraction methods were similar in the extraction of P fractions from soils, specially in the evaluation of P availability to flooded rice in the studied Histosols.

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