Gradual correction of phosphorus availability in the no-tillage system[1]

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ABSTRACT

In areas cultivated under no-tillage system, the availability of phosphorus (P) can be raised by means of the gradual corrective fertilization, applying phosphorus into sowing furrows at doses higher than those required by the crops. The objective of this work was to establish the amount of P to be applied in soybean crop to increase content of P to pre-established values at the depth of 0.0 to 0.10 m. An experiment was carried out on a clayey Haplorthox soil with a randomized block experimental design distributed in split-split plot, with four replications. Two soybean crop systems (single or intercropped with *Panicum maximum* Jacq cv. Aruana) were evaluated in the plots. In addition, it was evaluated four P levels (0, 60, 120 and 180 kg ha^{-1} P_2O_5) applied in the first year in the split plots; and four P levels (0, 30, 60 and 90 kg ha^{-1} P_2O_5) applied in the two subsequent crops in the split-split plot. Contents of P were extracted by Mehlich-1 and Anion Exchange Resin methods from soil samples collected in the split-split plot. It was found that it is necessary to apply 19.4 or 11.1 kg ha^{-1} of P_2O_5, via triple superphosphate as source, to increase 1 mg dm^{-3} of P extracted by Mehlich-1 or Resin, respectively, in the 0.0 to 0.10 m layer of depth. The soil drain P character decreases as the amount of this nutrient supplied in the previous crops is increased.

Key words: anion exchange resin, corrective fertilization, Mehlich-1, triple superphosphate.

RESUMO

Correção gradual da disponibilidade de fósforo no Sistema Plantio Direto

Em áreas cultivadas no Sistema Plantio Direto, pode-se elevar a disponibilidade de fósforo por meio da adubação corretiva gradual, aplicando-se, no sulco de semeadura, quantidade de P superior à requerida pela cultura. Este trabalho foi realizado com o objetivo de se estabelecer a quantidade de P a ser aplicada no cultivo de soja, visando a elevação do teor de P para valores pré-estabelecidos, na camada de 0 a 0,10 m de profundidade. Conduziu-se um experimento em Latossolo Vermelho distroférrico típico, textura muito argilosa, com delineamento experimental de blocos ao acaso, distribuído em parcelas sub-subdivididas, com quatro repetições. Foram avaliadas duas formas de cultivo de soja (solteiro e consorciado com *Panicum maximum* cv. Aruana) nas parcelas; quatro doses de P (0, 60, 120 e 180 kg ha^{-1} de P_2O_5) aplicadas no primeiro ano, nas subparcelas; e quatro doses de P (0, 30, 60 e 90 kg ha^{-1} de P_2O_5) aplicadas em dois cultivos subsequentes, nas sub-subparcelas. Efetuou-se a extração dos teores de P por Mehlich-1 e Resina de Troca Aniônica em amostras de solo coletadas nas sub-subparcelas. Verificou-se que há necessidade da aplicação de 19,4 ou 11,1 kg ha^{-1} de P_2O_5 na semeadura da soja, usando-se superfosfato triplo como fonte, para a elevação de 1 mg dm^{-3} de P extraído por Mehlich-1 ou Resina, respectivamente, na camada de 0,0 a 0,10 m de profundidade. Há diminuição do caráter dreno de P do solo, a medida em que se aumenta a quantidade do nutriente fornecida no cultivo anterior.

Palavras-chave: adubação corretiva, superfostato triplo, Mehlich-1, Resina Trocadora de Ânions.

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INTRODUCTION

The corrective phosphate fertilization, aiming at incorporating new areas or degraded areas into the farming process, has traditionally been carried out by incorporating phosphate fertilizer with some agricultural implement, as a way of rising nutrient availability in the top soil layer, usually 0.20 m of depth.

However, in areas that have been cultivated for some years, especially those properly managed under no-tillage system (NTS), without limitations related to physical impediments to the growth of the root system, it has been chosen to increase the availability of P by means of gradual corrective phosphate fertilization. In this case, in which there is no possibility or incorporation of phosphate fertilizer into a soil layer is not wanted, an amount of P greater than that required by the crop, in terms of extraction and export of the nutrient, is applied in the sowing furrow, with the objective of a gradual accumulation of phosphorus in the soil so as to achieve the target availability even after some years.

This management has been adopted from the premise that the dynamics and availability of P in the soil is promoted in no-tillage system since the lack of soil disturbance associated with the plant cover, besides minimizing the effects of erosion, facilitates mechanism of nutrient diffusion as a result of the increase in the available water. Furthermore, it decreases the contact between the soil colloids and phosphate ion, reducing the adsorption reactions (Carneiro *et al*., 2011). The mineralization of organic residues can also provide the release and redistribution of organic forms of P, more mobile in the soil and less susceptible to adsorption reactions (Rheinheimer & Anghinoni, 2003). In addition, it can keep a continuous flow of different forms of C that compete with the phosphate ions for the positive load sites of inorganic colloids and they complex ions Al^{3+} and Fe^{3+}, forming complexes and stable water-soluble compounds, resulting in the increase in the availability of P to the roots.

In the available technical information for soybean crop in the Central region in Brazil (Embrapa Soja, 2011), is proposed for the *Cerrado* region, the application of up to 100 kg ha^{-1} of P_2O_5, according to the nutrient content class (very low or low) and on the content class of clay in the soil. Thus, it is expected that in a maximum period of six years, the P levels will be raised to a level considered good, whose value can vary from 3 mg dm^{-3} of P extracted by Mehlich-1 for soils with more than 600 g kg^{-1} of clay, and 18 mg dm^{-3} for soils with less than 200 g kg^{-1} of clay.

In this context, it is noteworthy that the professionals of technical assistance show doubts about the amount of P needed in the gradual corrective fertilization to increase the nutrient availability to a given targeted content.

The objective of this work was to set the amount of phosphorus to be applied in soybean sowing line grown under no-tillage system with the purpose of increasing the content of P extracted by Mehlich-1 and Anion Exchange Resin in the layer from 0 to 0.10 m of depth for pre-established values.

MATERIAL AND METHODS

The experiment was carried out in Dourados, State of Mato Grosso do Sul, under very clayey Hapludox soil, in an area previously cultivated with *Urochloa brizantha* (Stapf) Webster cv. Marandu for a period of eight years. The experimental design was a randomized block design, distributed in split-split plot design with four replicates, evaluating two forms of soybean cropping (single and intercropped with *Panicum maximum* Jacq. cv. Aruana.) in the plots. In November 2009, it was applied in the sowing furrow, four doses of phosphate fertilizer (0, 60, 120 and 180 kg ha^{-1} P_2O_5, using triple superphosphate as a source) and basic fertilization (60 kg ha^{-1} of K_2O and 6 kg ha^{-1} Zn via potassium chloride and zinc sulphate as sources, respectively) in the split plot; in October 2010, the split plot were divided into four split-split plot, where it was applied four other P levels (0, 30, 60 and 90 kg ha^{-1} of P_2O5) and basic fertilization (60 kg ha^{-1} of K_2O and 3 kg ha^{-1} Zn), using the same sources of the previous year. In October 2011, the application of phosphate fertilizer treatments in split-split plot was repeated, along with the supply of 60 kg ha^{-1} K_2O. In the three years of conducting the experiment, the fertilizers were applied manually before sowing in furrows with about five centimeters of depth, open by seeder discs. After manual application of fertilizers, the furrows were covered with mattock.

The plots, split plot and split-split plot had 400 m² (10 x 40 m), 100 m² (10 x 10 m) and 25 m² (5 x 5 m) of area, respectively. Soybean was sowed at spacing of 0.60 m, in the years 2009, 2010 and 2011 under no-tillage system. Aruana-grass was sown in between rows of the soybean, around 15 to 20 days after the emergence of the latter. After the soybean harvest, plots in the intercropping system remained with the forage, whereas the plots corresponding to the single cultivation were grown with oat.

Before experiment establishment, chemical and physical characterization of soil samples collected in the layers 0 to 0.10 and 0.10 to 0.20 m of depth, using dutch auger were performed according to Silva *et al*. (1999) (Table 1). For each depth, the composite sample consisted of 20 single samples randomly collected in the experimental area. On June 15, 2012, another collection of soil samples were carried out at depths 0.0 to 0.05 and 0.05 to

0.10 m, opening a trench in each plot in the transverse direction to the crop row. Sampling was carried out with the aid of a PVC trough and a stainless steel spatula, removing a slice of about 0.01 m in thickness, 0.60 m in length and width corresponding to the depth of the sampling (0.05 m). To collect the soil sample, one of the edges of the PVC trough was positioned on the trench wall and the slice of about 0.01 m thick was removed with the stainless steel spatula, with length corresponding to 0.30 m of each side of the crop row. Therefore, such as soybeans had been planted at spacing of 0.60 m, the collected sample covered the space of two consecutive lines. It was decided to restrict the collection of soil samples to only of the two aforementioned layers, considering the depth of application of phosphate fertilizer at sowing line (0.05 m) and the absence of soil disturbance in the no-tillage system. In these samples, the extraction of phosphorus was done by Mehlich-1 (HCl 0.05 mol L^{-1} + H_2SO_4 0.0125 mol L^{-1}) according to Silva *et al*. (1999), and Anion Exchange Resin according to Raij & Quaggio (2001), followed by quantification by molecular absorption spectrophotometry. For each extractor used, the P content was also set in the layer from 0.0 to 0.10 m by means of arithmetic average of the values determined in soil samples collected at depths from 0.0 to 0.05 and 0.05 to 0.10 m.

The data obtained in this experiment were submitted to analysis of variance and the effect of the forms of soybean crop was compared by means of orthogonal contrasts technique at 5% of probability. The effect of phosphorus fertilization on the levels of this nutrient, extracted by Mehlich-1 and Anion Exchange Resin methods, in the layers 0.0 to 0.05, 0.05 to 0.10 and 0.0 to 0.10 m of depth, was given by the adjusted regression model, using the SAEG software v. 9.1 - 2007. Among the tested regression models (linear, quadratic, cubic, square root, potential, exponential and hyperbolic), it was defined for each set of variables, the one with the highest coefficient of determination, whose estimators of equation parameters were significant at 5% probability, at least.

RESULTS AND DISCUSSION

The contents of phosphorus in the soil, extracted by Mehlich-1 and Resin methods in layers 0.0 to 0.05 and from 0.05 to 0.10 m of depth, were numerically higher in the plots where the single crop was grown, in relation to intercropping with *Panicum maximum* cv. Aruana; however, the differences found in this experiment did not differ significantly at 5% probability, according to the technique of orthogonal contrasts (Table 2).

This difference is probably not associated with the greater extraction and export of P by the intercropped soybeans, inasmuch as the grain yield did not differ significantly from the soybean grown in the single crop (Kurihara *et al*., 2011). In this experiment, in the third year of evaluation, the amount of P accumulated in the aerial part of Aruana grass grown between rows of soybean was estimated, in three harvests, carried out on the day when the legume was harvested and on days 51 and 145 after harvest. It was found that the Aruana grass produced, in these three cuts, 4,397 kg ha^{-1} of aerial part dry matter, where the equivalent of 21.55 kg ha^{-1} P_2O_5 was accumulated (unpublished data). Thus, it can be assumed that the availability of P observed in intercropped soybean crop condition, although statistically similar to that observed for soybean in single crop, may be associated with immobilization of some of the nutrient accumulated in the straw of Aruana grass, which remained on the soil surface after the forage management.

It is pointed out that this P immobilization in the aerial part of Aruana grass presents itself as a positive aspect of intercropping, since the gradual mineralization of the straw of this forage allows the greater use efficiency of the nutrient, due to the minimization of adsorption of the soil (Novais & Smyth, 1999).

In the second and third years of soybean cultivation (P_{2and3}), four levels (0, 30, 60 and 90 kg ha^{-1} P_2O_5) of P was applied in the sub-subplots in each subplot where other four doses (0, 60, 120 and 180 kg ha^{-1} P_2O_5) had been applied in the first crop (P_1). For the evaluation of the unfolding of the interaction of P_{2and3} effect within P_1, it was chosen to

Table 1: Chemical and physical characterization of soil samples collected in two depths in the experimental area before application of phosphate fertilization

Depth	pH H_2O	Al	Ca	Mg	K	P	V	O.M.
m		cmol$_c$ dm^{-3}				mg dm^{-3}	%	g kg^{-1}
0.0 to 0.1	5.7	0.0	3.9	2.0	0.38	6.1	56	29.2
0.1 to 0.2	5.7	0.0	4.0	1.8	0.31	4.3	58	24.8

	Cu	Fe	Mn	Zn	Clay	Silt	Sand
	mg dm^{-3}				g kg^{-1}		
0.0 to 0.1	11.7	32	67	1.0	720	135	145
0.1 to 0.2	12.0	31	56	0.7	737	118	145

[1]Al, Ca and Mg extracted by KCl 1 M and P, K, Cu, Fe, Mn and Zn extracted by Mehlich-1 (HCl 0.05 M + H_2SO_4 0.0125 M).

consider the total amount applied to the second and third crops (Figure 1). Thus, it was found that the contents of P in the soil, determined by both Mehlich^{-1} extractant and the Resin methods, as well as the observed increase in this variable in response to P_{2and3} were very similar in conditions where phosphate levels in the first year (P_1) was null or limited (up to 60 kg ha^{-1} P_2O_5). The similarity of response to P_{2and3}, found in both extraction methods, is shown in Figure 1 by the proximity of the angular coefficients of the regression equations adjusted for P_{2and3} effect in P_1 = 0 and P_1 = 60. For the Mehlich-1 extractor, for example, the angular coefficients of 0.05345 and 0.04959, obtained for ratios P_{2and3}: P_1 = 0 and P_{2and3}: P1 = 60 indicate that in Haplorthox soil every 100 kg ha^{-1} of P_2O_5 applied in soybean sowing line, an increase of 5.345 and 4.959 mg dm^{-3} of P occurs in the layer from 0.0 to 0.10 m of depth.

On the other hand, when 120 kg ha^{-1} of P_2O_5 was applied in the first crop, the P content in the soil were considerably higher than that observed for P_1 = 0 and P_1 = 60, remaining, still, linear increases in response to $P_{2and3,}$ close in magnitude to them, regardless of the analytical method used. Yet, with the application of 180 kg ha^{-1} of P_2O_5 in the first year, the increases in the availability of P, found with both evaluated extractants in response to P_{2and3}, were more marked than that found in other treatments, due to the lower P adsorption capacity when the soil is previously fertilized with a higher amount of calcium. Under conditions of consecutive additions of P in the no-tillage system, the adsorption of the nutrient occurs primarily in the most avid sites, with lower lability, and then the remaining phosphorus is redistributed into fractions retained with lower energy and greater availability to plants (Rheinheimer *et al*., 2000). Because the spacing adopted in soybean crop was 0.60 m, there could have been doubts as to the location of the furrow of fertilizer deposition and seeds coincides in the three years in which the experiment was carried out. However, as the sowing furrow was always allocated from the same edges of the experimental area, the manual deposition of fertilizers was carried out in a location rather close in relation to the previous year. Indeed, the decrease in the drainer character of the soil P, verified after fertilization with 180 kg ha^{-1} P_2O_5 in the first year, allows to suggest that, indeed, the manual distribution of nutrients was carried out in locations very close to each other in three years. By using again the Mehlich-1 extractor as an example, it is found for the ration P_{2and3}: P_1 = 180, an angular coefficient of 0.1109, which enables to infer that the increase provided into nutrient availability in soil, by applying 100 kg ha^{-1} P_2O_5 in soybean sowing row (11.09 mg dm^{-3} P) is as twice as much of that found in the absence of phosphate fertilizer in the first year (5.345 mg dm^{-3} P). Decreases in P drain character in the soil, as the amount of nutrient applied increases, were also observed by Carneiro *et al*. (2011), in clay texture Haplorthox. These authors found more significant increase in the fractions of labile inorganic and moderately labile P in soil cultivated for more than ten

Table 2: Summary of the analyses of variance, means and orthogonal contrasts for contents of phosphorous set by Mehlich-1 and Anion Exchange Resin at the layers 0.0 to 0.05 and 0.05 to 0.10 m of depth in function of the soybean crop forms (single and intercropped with *Panicum maximum* cv. Aruana)

Variation Source [1]		Mehlich -1		Resine	
	D.F.	0.0 to 0.05	0.05 to 0.10	0.0 to 0.05	0.05 to 0.10
			Error mean square		
Block	3	24.7	11.1	337.9	48.1
Crop	1	114.3	127.1	467.2	67.7
Error (a)	3	61.4	6.8	38.6	3.5
P_s	3	286.6	139.2	575.7	631.0
P_s x C	3	28.1	14.0	249.8	109.7
Error (b)	18	17.7	3.6	125.7	14.0
P_{ss}	3	1.648.3	250.9	4.881.3	1.229.1
P_{ss} x Crop	3	39.5	6.6	68.7	17.4
P_{ss} x P_s	9	109.1	19.8	170.7	61.7
P_{ss} x P_s x Crop	9	35.9	2.8	56.6	34.0
Residue	72	33.1	5.9	116.9	23.9
			Means		
Single		20.5	10.6	47.2	26.1
Intercropped		18.6	8.6	43.3	24.6
			Orthogonals contrasts		
Single x intercropped		1.9$^{n.s}$	2.0$^{n.s}$	3.8$^{n.s}$	1.5$^{n.s}$

[1]P_s and $P_{ss.}$ = Doses of phosphorous in the subplots and sub-subplots, respectively.

years in the no-tillage system, in relation to an adjacent soil under condition of native *Cerrado* vegetation after the fertilization of bean crop with four doses of P. In this study, the largest increase in the availability of P in soil previously cultivated with soybeans and corn was probably occupying sites of P fixation in the soil, which led to lower adsorption of P applied in the experiment.

It is highlighted in Figure 1 that for the same total amount of P applied in the three years of soybean cultivation, there are differences in certain nutrient content in samples collected at a depth from 0.0 to 0.10 m, by both extractants, in function of the manner in which the corrective fertilization was carried out. For the Mehlich-1 extractant, for example, it is estimated that the application of 180 kg ha^{-1} of P_2O_5 in the first year (P_1 = 180 and P_{2and3} = 0) resulted in the content of 7.91 mg dm^{-3} of P (value corresponding to the intercept of the regression model adjusted for the interaction P_{2and3}: P_1 = 180). When fertilization consisted of applying 120 + 30 + 30 kg ha^{-1} P_2O_5 in the first, second and third year, respectively (P_1 = 120 and P_{2and3} = 60), a content of 13.67 mg dm^{-3} P was set (value estimated from the regression model equation adjusted for the interaction P_{2and3}: P_1 = 120, considering x = 60). However, when annual fertilization was carried out with 60 kg ha^{-1} P_2O_5 (P_1 = 60 and P_{2and3} = 120), it was obtained in the third year, a content of 14.81 mg dm^{-3} P (estimated from the equation adjusted for the interaction P_{2and3}: P_1 = 60, considering x = 120). On the other hand, in the absence of P supply in the first year, followed by application of 90 kg ha^{-1} P_2O_5 in two subsequent crops (P_1 = 0 and P_{2and3} = 180), the final nutrient availability was 16.97 mg dm^{-3} P (estimated from the equation adjusted for the interaction P_{2and3}: P_1 = 0, considering x = 180). Similarly, it was estimated that the availability of P determined by Resin after three years of cultivation was 24.95; 34.12; 35.55 and 40.82 mg dm^{-3} to P, respectively at the four forms of the aforementioned corrective fertilization. In short, for the same amount of P applied in soybean sowing furrow (180 kg ha^{-1} P_2O5), a decrease occurred in its availability in the soil as its proportion, which was applied before, was increased. Certainly, this reduction in the availability of P in the fertilizer application time is less intense than what would occurred whether the nutrient were incorporated into the soil in the

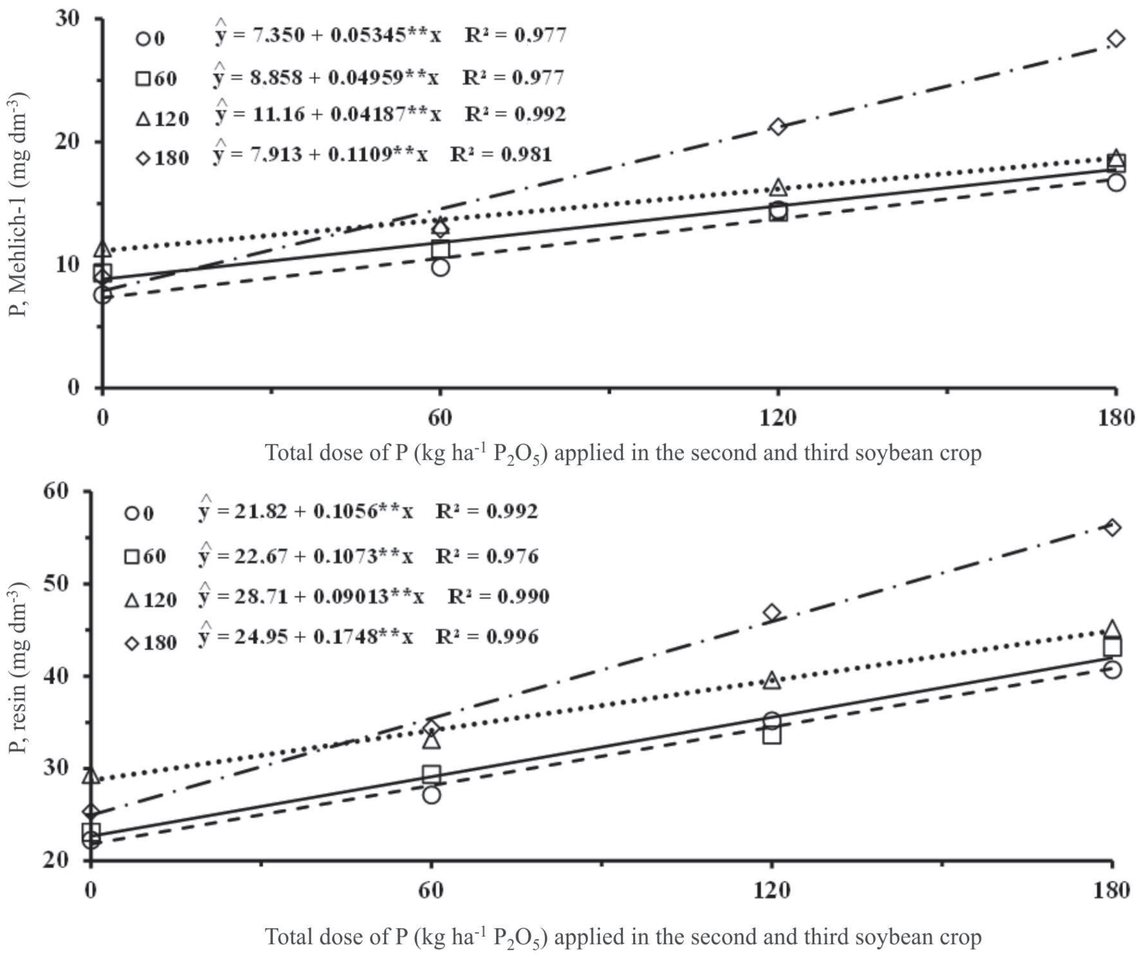

Figure 1: Content of P in Haplorthox soil with very clay texture at the depth of 0.0 to 0.10 m, set by Mehlich-1 and Resine methods in function of phosphate fertilization in the soybean sowing row in two consecutive crops (2010/2011 e 2011/2012), associated with the application of four doses of P in the sowing row in the first crop year(2009/2010).

layer 0.0 to 0.20 m, with some agricultural implement. This consideration becomes evident from results obtained by Nunes *et al*. (2011), in a dystrophic red latosol in Planaltina, Federal District, grown for 14 years with soybeans and corn in the summer and millet in the last six winter crops, when 80 kg ha^{-1} year^{-1} of P_2O_5 was applied as triple superphosphate. Under these conditions, these authors found that in the layer from 0.0 to 0.10 m of depth, the average content of Bray-1 extractable P determined in no-tillage system was about 70% higher than in the conventional tillage. However, they point out that this difference is also explained by a fertilizer dilution effect during the soil tillage at 0.20 m with the plow discs in conventional tillage.

When the effect of the total amount of P applied to the soil was evaluated in the three year set, regardless of the form of cultivation (single or intercropping), on the availability of this nutrient in layers 0.0 to 0.05 and 0.05 0.10 m, determined by Mehlich-1 and Resin methods (Figure 2), the presence of considerably higher levels in the superficial layer was found. This result is expected and due to the consecutive addition of fertilizer in the surface layer, associated to the absence of disturbance, return of P absorbed by plants to the surface by deposition of plant residues on the soil and decrease in the erosion rates in no-tillage system (Tokura *et al*., 2002; Rheinheimer *et al.*, 2008; Nunes *et al*., 2011). Furthermore, for both analytical methods, the angular coefficients of the adjusted regression equations are considerably higher in the layer from 0.0 to 0.05 m, pointing to a less adsorption of P. This is probably due to the higher content of available organic matter in the surface layer (36.4 g kg^{-1}) than in the layer 0.05 to 0.10 meters (27.7 g kg^{-1}), where this variable is negatively correlated with the maximum capacity of phosphorus adsorption (MCPAs) according to Silva *et al*. (1997). According to Castoldi *et al*. (2012), the organic matter is one of the main factors related to the adsorption of P because its interaction with Al and Fe oxides reduces the adsorption sites by coating the surface of these oxides by molecules of humic, acetic and malic acids, or by the formation of compounds in the soil solution. In soils with

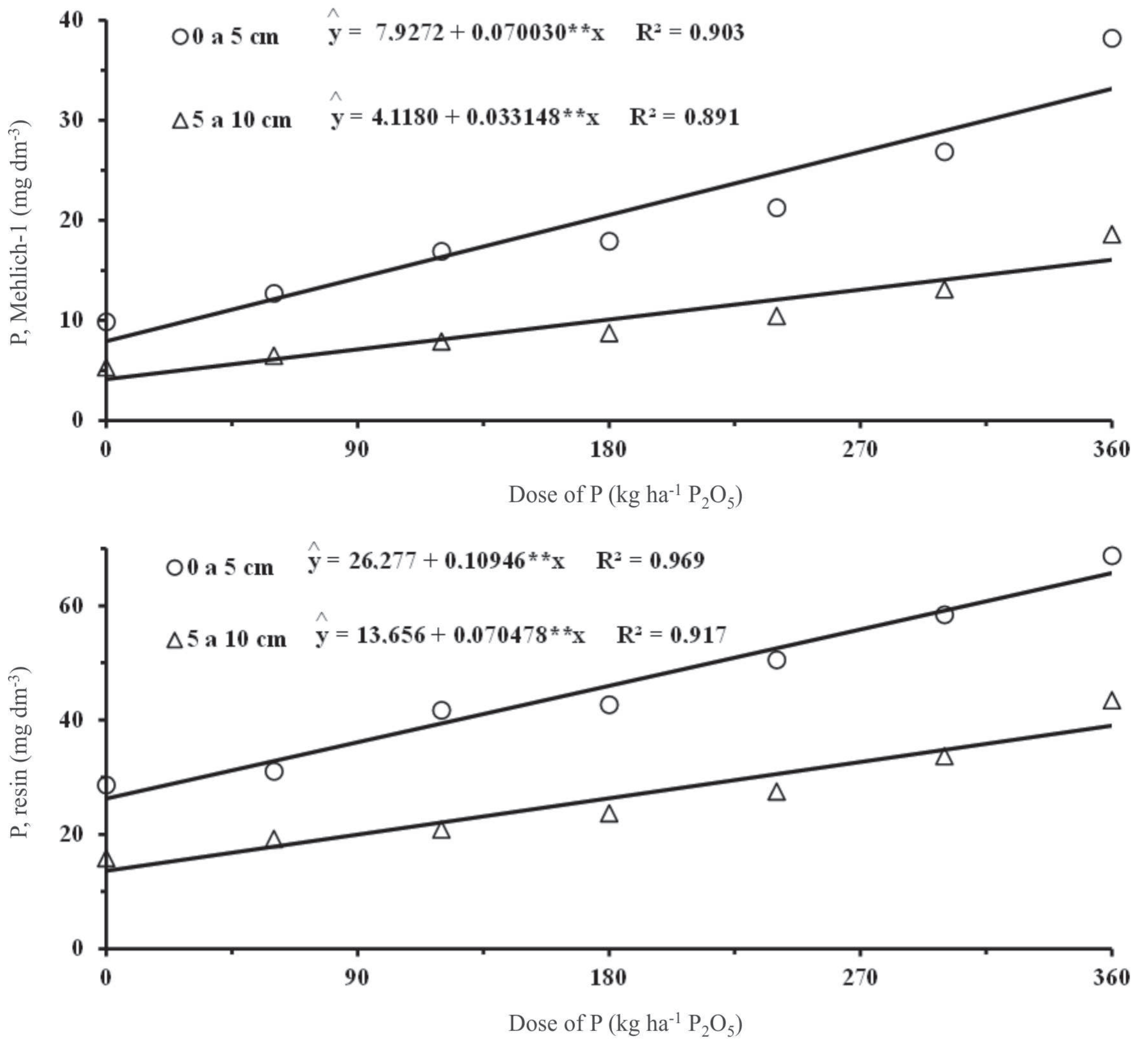

Figure 2: Content of P in Haplorthox soil with very clay texture at the depth of 0.0 to 0.05 m and 0.05 to 0.10 m, set by Mehlich-1 and Resin methods in fucntion of the doses of P applied in the soybean sowing row in three consecutive crops.

higher organic matter content, there is a higher organic carbon contribution and better soil conditions for microbial activity, providing microorganisms the use of the P adsorbed in Fe and Al oxides and, consequently, the recycling of this nutrient (Silva *et al*. 1997). Thus, there is a tendency of lower fixation as the plant uses better the P from the phosphate fertilizer. In addition, Bahia Filho (1982), cited by Silva & Braga (1992), mentions that the capacity of Mehlich-1 to recover P is higher in soils with high organic matter content due to the lower consumption of hydrogen in the protonation of hydrated oxides of iron and aluminum surfaces and thus less exhaustion of the extractant.

Considering the average content of P in the layer from 0.0 to 0.10 m under the effect of the total amount of P applied to the soil, it was found that in a typical clayey Haplorthox cultivated with soybean under the no-tillage system, an increase of 0.0516 mg dm^{-3} of P extracted by Mehlich-1 method occurred for every kg ha^{-1} of P_2O_5 applied at sowing line according to the angular coefficient of the adjusted regression equation in Figure 3. By means of direct calculation of the ratio between these variables, it can be estimated that application of 19.4 kg ha^{-1} P_2O_5 (equivalent to 43.1 kg ha^{-1} triple superphosphate, considering a content of 45% P_2O_5) is required in soybean sowing row for raising 1 mg dm^{-3} of P extracted by Mehlich-1 method, in the layer from 0.0 to 0.10 m of depth. Similarly, the raise of 0.0900 mg dm^{-3} of P extracted by the Resin method for every kg ha^{-1} of P_2O_5 applied (Figure 3) allows one to infer that there is a need for fertilization with 11.1 kg ha^{-1} P_2O_5 (equivalent to 24.7 kg ha^{-1} triple superphosphate) in soybean sowing row for raising 1 mg dm^{-3} of P, in the layer from 0.0 to 0.10 m of depth. These estimates are relatively close to those established by Schlindwein & Gianello (2008), from the pooled analysis of results from several experiments conducted in Rio Grande do Sul, under no-tillage system in various types of soils. According to these authors, for soils with more than 550 g kg $^{-1}$ of clay, the intake of 19.0 and 8.4 kg ha^{-1} of P_2O_5 is needed in soybean sowing to provide the increment of 1 mg dm^{-3} of P extracted by the Mehlich-1 and Resin, respectively, in the layer of 0.0 to 0.10 m, associated with the supply of the estimated amount of P required for obtaining 90% of the maximum yield obtained in the experiments. In addition, it is estimated that in soils with clay content ranging from 400 to 550 g kg^{-1}, to provide the increment of 1 mg dm^{-3} of P extracted by Mehlich-1 and Resin methods, it is necessary to provide 11.8 and 4.2 kg ha^{-1} P_2O_5, respectively. For soils with 110 to 400 g kg^{-1} of clay, an unit increase in the P content determined by those extractants is achieved by applying 6.0 to 3.0 kg ha^{-1} of P_2O_5, respectively.

On the other hand, Nunes *et al*. (2011) established that the intake of 37 kg ha^{-1} P_2O_5 is necessary for increasing 1 mg dm^{-3} of P, extractable by Bray 1 in the layer 0.0 to 0.10 m, in a clayey dystrophic red latosol, cultivated for 14 years in the no-tillage system with soybeans and corn in the summer and millet as cover crop in the last six winter crops.

It is noted, however, that both inferences should be considered only as a reference for indicating gradual corrective phosphate fertilizer in no-tillage system. As previously discussed, the increases in the availability of P in the soil propitiated by phosphate fertilization may also be influenced, among other factors, by the initial content of this nutrient, by time after corrective fertilization in sowing furrows and by the depth of soil sampling. It is also important to note that the estimates aforementioned were obtained in soybean growing conditions with spacing of 0.60 m between rows. For spacing of 0.45 m, usually adopted in single crops of this legume, the fertilizer will be distributed in an area 33.3% greater in the sowing furrow, so that the contact surface between the P applied and the

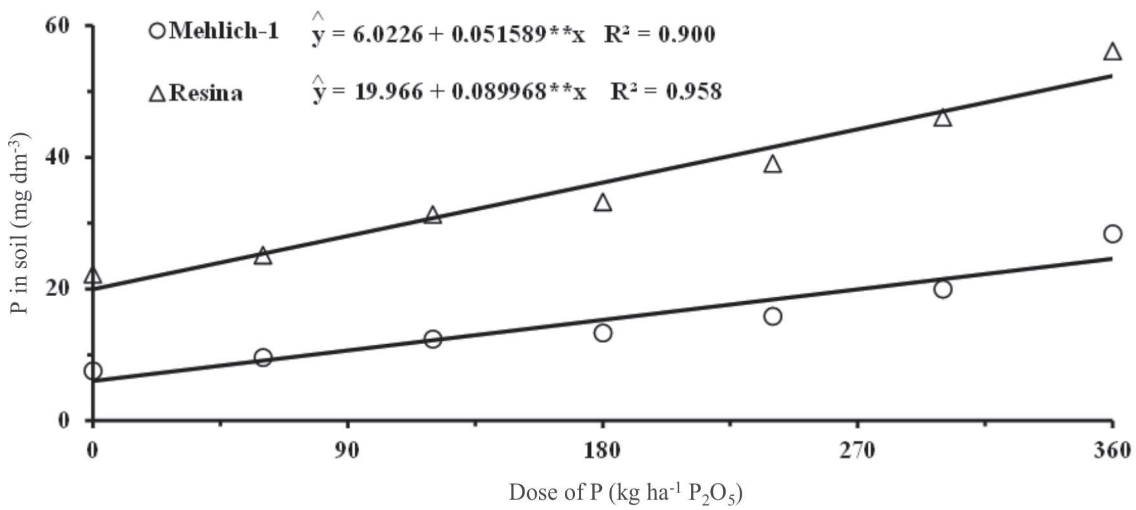

Figure 3: Content of P in Haplorthox soil with very clay texture at the depth of 0.0 to 0.10 m, set by Mehlich-1 and Resine methods in function of the doses of P applied in the soybean sowing row in three consecutive crops.

soil, and consequently, the adsorption of this nutrient may also be increased.

The contents of P determined by the extractant Resin in all soil samples collected in the experiment (two cropping systems, two sampling depths, and combination of four P doses in the first crop year associated with four doses applied in the second and third year) were positively and highly significant correlated to the contents extracted by Mehlich-1, ($y = 9.6213 + 1.7609x$, $r = 0.958$ **). This direct and significant correlation is expected, considering that it is about soil samples collected in one site, where different doses of a single source of P were applied. In terms of evaluation of different sources and forms of application of the nutrient as well as different types of soils in terms of texture, clay mineralogy and availability of organic matter, a total lack of correlation between these two variables has been checked (Barbosa Filho *et al*., 1987; Holanda *et al*., 1995 and Sobral *et al*., 2008)

This lack of correlation is verified by the fact that the Mehlich-1 extractant, made up by mixing two diluted strong acids (HCl 0.05 mol L^{-1} + H_2SO_4 + 0.0125 mol L^{-1}), has its extraction action by protonating P in soil by means of anion exchange in which the radicals chloride and mainly the sulfates replace the phosphate linked to calcium and to a lesser extent, linked to aluminum and iron (Rheinheimer *et al*., 2008). In addition, sulphate ions act by reducing the phosphorus resorption in the soil during the extraction process. However, in clayey soils, especially those with higher pH, the power of extraction may be depleted by the soil itself since the initial pH of the extractant, which is 1.2, is rapidly increased. Likewise, the SO_4^{2-} of the extractant, which acts by exchanges with the adsorbed phosphate is also rapidly adsorbed by the soil, losing the extraction power (Novais & Smyth, 1999; Novais *et al*., 2007). Thus, clayey soils have values of the critical levels lower than the sand soils, as in the former, depletion of the extractant is more marked than in the others (Novais & Smyth, 1999). On the other hand, the resin does not have its depletion power changed in function of the capacity factor of the soil (Novais & Smyth, 1999), which is why the extracted contents are interpreted independently of the texture of the analyzed sample and the values are higher than those extracted by Mehlich-1, as shown in Figure 6. Bortolon *et al*. (2009) emphasized, however, that the larger extraction of P by double acid extractant, in relation to the resin, does not necessarily occur in sandy soils

Barbosa Filho *et al*. (1987) applied triple superphosphate at a dose equivalent to 200 mg dm^{-3} of P in samples from two latosols with different clay content, organic matter and nutrient inorganic fractions. After evaluating the extractable P content in four incubation periods, they found no linear correlation between the Mehlich-1 and Resin extractants, which, according to the authors, was due to the fact that the Mehlich-1 extract predominantly the fractions P-NH_4Cl and P-Fe and the Resin extract mainly the P-Al fraction

The lack of a significant correlation between the levels extracted by Mehlich-1 and Resin also occurs when naturally rich P-Ca in soils or those fertilized with low reactivity natural phosphates are included in the evaluation. Under these conditions, the acid extractant tends to overestimate the availability of P, while the Resin is not sensitive to non-labile forms, such as the P-Ca (Novais *et al*., 2007).

CONCLUSIONS

In a clayey Haplortox typical soil cultivated with soybeans in no-tillage system, it is possible to increase the availability of P by gradual corrective phosphate fertilization, in which the application of 19.4 or 11.1 kg ha^{-1} P_2O_5 (equivalent to 43.1 and 24.7 kg ha^{-1} triple superphosphate) is required at sowing row for raising 1 mg dm^{-3} of P extracted by Mehlich-1 or Resin method, respectively, in the layer 0.0 to 0.10 m of depth.

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