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Crop growth response and dynamics of inorganic phosphorus fractions after application of reactive Arad phosphate rock in Oxisol with different land use histories

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Adsorbed or precipitated phosphorus can be susceptible to dissolution depending upon environmental conditions. This work evaluated both the partitioning and availability of the inorganic forms of P bound to Al, Fe and Ca in samples of a clayey Dystrophic Red Latosol (Oxisol) (DRL) with different land use history, fertilized with Arad reactive natural phosphate in Goias State, Brazil. The inorganic fractions of Al-P, Fe-P and Ca-P and the contents of Mehlich-1, ion-exchange resin, citric acid and Olsen extracted available P were determined in DRL. Plants grown in soil previously cultivated produce more beans than plants grown in soil not previously cultivated. The fractions Al-P and Fe-P represent the main inorganic forms in clayey DRL, being phosphorus availability closely related with the fraction Al-P. The distributions of the inorganic fractions of P in the soil fertilized with reactive phosphate were Fe-P = 45%, Al-P = 40% and Ca-P = 15%. The phosphorus content determined by alkaline extraction (Olsen Method) was closely related to levels of Al-P and Fe-P. On other hand, the concentrations determined by extracting acids (Mehlich-1 and citric acid) were more related to the Ca-P fraction. Fe-P and Al-P inorganic forms stocked over time with successive fertilizations in Oxisol with a history of cultivation in no-tillage may return to soil solution and provide the nutrient demand of plants.

Key words: Cerrado soil, phosphorus fertilization, phosphorus fractionation, inorganic phosphorus.

INTRODUCTION

The low availability of P is regarded as the main constraint of the agricultural production under wet, tropical and subtropical conditions (Hinsinger, 2001). To solve this problem, farmers use fertilizers to supply the nutrients demand of crops. So, soils originally poor in nutrients, such as the Brazilian Cerrado, have their fertility improved in course of time and successive fertilizations. Nevertheless, P added to soil through fertilizers is poorly used by plants, the majority of it being accumulated in organic and inorganic forms. The increase

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Table 1. Chemical, physical and mineralogical attributes of the samples of the Dystrophic Red Latosol (Oxisol) (DRL), before the application of the treatments with P.

Soils	Use	pH H_2O	P-Mehlich-1	P-resin	P-rem	CMAP	K	V
					mg dm^{-3}			(%)
DRL	SNC	5.5	1.0	3.6	9.8	1139	43	11
	SC	5.7	11.6	37.0	14.6	994	123	45
		MO	Clay	Ct	Gb	Hm	Gt	
					g kg^{-1}			
DRL	SNC	32	570	203.1	115.9	4.7	35.1	
	SC	28	570	242.0	111.7	4.7	34.1	

SNC, Soil not cultivated previously; SC, cultivated soil. P-rem, remaining phosphorus; CMAP, maximum phosphorus adsorption capacity; MO, organic matter; Ct, kaolinite; Gb, gibbsite; Hm, hematite; Gt, goethite.

in the stocks and the likely modification in the P dynamics alter the response patterns of the crops to phosphate fertilization which become less significant when compared to newly opened land for agriculture (Resende et al., 2006).

Phosphorus can be found in soil bound to Fe, Al, Ca, silicate clays and oxides (Gatiboni et al., 2005). The forms of P either adsorbed or precipitated are stable, but they can be susceptible to dissolution and become again available to plants depending to the environmental conditions (Wright, 2009). In this way, only a small part of the P retained in soil is absorbed by the agricultural crops, for many factors influence the availability of the nutrient, for instance: the species cultivated (Li et al., 2008), the soil texture, the clay minerals, acidity (Rajan et al., 1996), the content of soil organic matter (Partelli et al., 2009), the doses, sources, particle size and form of application of fertilizers (Oliveira et al., 2008) and the soil tillage system (Pavinato et al., 2009; Zamuner et al., 2008).

In this context, in spite of the development of the several analytical methods, there is difficulty evaluating the availability of phosphorus in soil, for each method presents an extraction capacity related to the principle of chemical or physical action of the extractant and normally evaluates only a part of the available P. Therefore, the understanding of the occurrence of P forms in soil can support the choice of the method most suitable for the evaluation of P availability in each situation or the inclusion of new variables in the interpretation of the extracted P contents. This work evaluated the distribution and availability of P among inorganic forms bound to Al, Fe and Ca after fertilization with Arad reactive phosphate in a clayey Dystrophic Red Latosol (Oxisol).

MATERIALS AND METHODS

The soil samples used in this study were collected on the Alto Alegre Farm, localized in the municipality of Goias Planaltina, Goias State, Brazil, situated at 15° 20' 04'' of South latitude and 47° 34' 42" of de West longitude. The soil samples were collected from 0 to 20 cm depth, under two land use situations which were under native Cerrado vegetation (soil not cultivated previously) and the other in a neighboring cultivated area with both soybean and corn in no-tillage system for ten years. The cultivated area received annual application of 80 kg P_2O_5 ha^{-1}, the source used was Monoammonium Phosphate (MAP). In addition, in the year 2000, this area was given corrective phosphate fertilization with 650 kg ha^{-1} of Gafsa natural rock phosphate (28% P_2O_5).

The soil samples were subjected to the chemical and physical analysis methods (Silva, 2009) and mineralogical analysis (Resende et al., 1987). The soil was classified as clayey Dystrophic Red Latosol (DRL). The two samples exhibited contrasting attributes relative to both phosphorus and potassium contents, manifesting the condition of fertility constructed by the addition of fertilizers along the time in the area under agricultural use (Table 1).

The experiment was conducted in greenhouse at the Soil Science Department of the Federal University of Lavras, Lavras – Minas Gerais State, Brazil, in the year 2006. Pots with the capacity for four dm^3 of soil were used. The treatments consisted of soil samples from cultivated (SC) and non-cultivated (SNC) DRLs, to which four doses of P (0, 120, 240 and 480 mg dm^{-3}) were applied. The supply of P was accomplished on the basis of the total content of P_2O_5 in Arad reactive phosphate (30%). The experimental design was completely randomized in factorial scheme (2 × 4) with four replicates.

The samples in each pot were packed by utilizing calcium carbonate and magnesium carbonate p.a. to raise the base saturation to 70%. Also, the following amounts of nutrients (mg dm^{-3}): 100 of N; 100 of K were applied to the non-cultivated soil and 30 of K in the cultivated soil, 40 of S; 0.8 of B; 1.5 of Cu; 3.6 of Mn; 5.0 of Zn and 0.15 of Mo, in addition to the corresponding dose of P corresponding to each treatment. After 30 days of incubation with moisture controlled daily to 60% of the total volume of pores occupied by water, soil samples were collected from the pots for analysis of the chemical attributes. Next, six seeds of bean plant (*Phaseolus vulgaris* L. cv. Jalo Radiante) were sown per pot. At 12 days after planting, the seedlings were thinned to three plants per pot.

For the soil samples from cultivated area, potassium and nitrogen fertilizers at 300 and 150 mg dm^{-3} of N and K as side-dressing were applied while the soil samples from the previously non cultivated area received 300 and 300 mg dm^{-3} of N and K. In both cases, amount side-dressing fertilization was split into three applications. Throughout the period of the experiment, humidity was kept at 60% of the total volume of pores by adding deionized water. At 75 days after sowing, new soil samples from each pot were obtained for chemical analysis. Shoot plants were harvested and dried in oven forced air circulation at a temperature of 60°C during 72 h. Afterwards, the plants were weighed for obtaining the dry matter of the shoot, ground and analyzed for total contents of P (Malavolta et al., 1997).

The soil samples obtained after incubation and after the bean cultivation were subjected to the sequential extraction of inorganic phosphorus. The method consists of extracting forms of P bound to aluminum, iron and calcium. The aluminum-bound iron (Al-P) was extracted through the ammonium fluorite solution (0.5 M NH_4F at pH 8.2), the iron-bound phosphate (Fe-P) through the sodium hydroxide solution (0.1 M NaOH) and the calcium-bound phosphorus (Ca-P) by the sulfuric acid solution (0.25M H_2SO_4) (Chang and Jackson, 1957). The samples were also analyzed for available P using the extractants Mehlich-1 (HCl 0.05 mol L^{-1} + H_2SO_4 0.0125 mol L^{-1}) (Mehlich, 1953), ion-exchange resin (Raij et al., 1987), citric acid ($C_6H_8O_7$. 2% H_2O p/p) (modified of Dyer, 1894) and Olsen (0.5 M $NaHCO_3$) (Olsen et al., 1954). The phosphorus content determination in the extracts was accomplished by spectrophotometry, according to Braga and De Fellipo (1974). The data were subjected to analysis of variance and regression and multivariate analyses (Pearson's correlation and principal component analysis). All the mathematical and statistical operations were performed through computer programs Sisvar (Ferreira, 2011) and SPSS 15.0 (Statistical Package for Social Sciences).

RESULTS AND DISCUSSION

The average concentrations of P fractions bound to Al and Fe differed significantly in DRL under the effect of two historical usages. The soil cultivated presented higher contents of Al-P, Fe-P and available P than the soil not cultivated previously for ten years under no-tillage system. Aluminum bound P increased with increasing rates of reactive phosphate; this effect persisted even after harvest of the bean plant. The same trend was observed for the Fe-P fraction, but with less intensity compared with the Al-P (Table 2). For the Ca-P fraction, there was no difference between the soil with a history of cultivation and soil under an untilled system. Probably the Gafsa reactive phosphate applied to the area under no-tillage in year 2000 and Monoammonium Phosphate applied annually were dissolved and stored in the forms Al-P and Fe-P, indicating that in Cerrado conditions do not store P in Ca-P form. The level Ca-P too increased after application of Arad Rock Phosphate, but it had a quadratic behavior in function of the applied P doses, reaching a maximum of 70.6 mg kg^{-1} of Ca-P at a dose 352 mg kg^{-1} of P applied to soil.

It was observed that Al-P and Fe-P levels in soil were higher after bean grown than before planting. The fractions of inorganic P may have been affected by the contact time of reactive phosphate with soil or by the action of the plant through the exudation of organic acids by the rhizosphere (Shen et al., 2002; Hartwig et al., 2007), which can increase reactive phosphate solubilization. It was also observed that soil cultivated for ten years in an untilled system had higher levels of available P by different soil extractants (Mehlich-1, ion exchange resin, 2% citric acid and Olsen) than that of soil cultivated for the first time (Table 2). This increased P release after the application of reactive phosphate in the soil with a report of previous crops (soil with improved fertility) can be explained by the particular adsorption of phosphate groups coming from the fertilization performed each crop with Al and Fe oxides. Over time, that adsorption must reduce the amount of positive charges of oxides (Alleoni et al., 2009), saturating the components responsible for the phenomenon of phosphorus fixation. This causes the newly-added nutrients to remain under more labile forms; consequently, greater amounts could be extracted by means of the methods of available P analysis.

Bean plants grown in soil previously cultivated produced more shoot dry matter and grain than plants grown in soil not previously cultivated (Table 3). It can be seen that the response to application of phosphate fertilizer was more notable in not previously cultivated soil than in previously cultivated soil. The linear behavior of grain production in function applied P doses shows that bean maximum production capacity grown in soil not previously has not been reached, because soil phosphorus concentrations limited the production. On the other hand, there was no response to applying phosphate fertilizer in soil cultivated previously, since unfertilized plants produced the same amount grain than plants that received 480 mg dm^{-3} P. This indicates that phosphorus applied prior to the experiment, probably linked to aluminum, iron and calcium can return to the soil solution and be absorbed by plants.

Partitioning and dynamics of inorganic P in soil

Figure 1 shows percentage values of Al-P, Fe-P and Ca-P before and after bean growth in the pots, relative to the sum of three inorganic fractions P in the Latosol non-cultivated previously (Oxisol) comparing with Latosol cultivated for ten years in no-tillage system. In both soils, fraction Fe-P was dominant at the dose zero, which is related to the high contents of goethite and hematite of soil (Table 1) as compared with other Latosols of the region. In the soil not cultivated previously, before bean plant cultivation, the fraction Fe-P represented 72% of the total inorganic P and after cultivation, Fe-P decreased to 64%. In the soil cultivated previously, Fe-P represented 57% of total inorganic phosphorus and did not range in percentage terms after the bean cultivation. This different behavior indicates that in Latosol non-cultivated previously Fe-P has greater contribution to available P than in the soil cultivated previously; this may be due P smaller amount in all P inorganic fractions of soil non-cultivated previously when compared with soil cultivated for long time.

In applying the reactive natural phosphate fertilizer, there was alteration in the percent distribution of the fractions of phosphorus. The fraction Fe-P decreased in percentage terms in relation to the Ca-P, which is related with the nature of reactive phosphate, slow–solubilizing calcium phosphate. Nevertheless, the fraction Fe-P possibly has preference in the bindings, because they

Table 2. Fractions of Al-bound phosphorus Al (Al-P), Fe (Fe-P) and Ca (Ca-P) in DRL (Oxisol) and P available by different extractor both before and after the bean plant cultivation, influenced by the report of previous soil use and doses of reactive phosphate.

Sampling	Historic	Doses of P (mg dm^{-3}) 0	120	240	480	Mean	Equations	R^2
				Al-P (mg dm^{-3})				
Before planting	SNC	17	22	31	51	30[b]	$Y=0.0740^{**}x+14.45$	0.98
	SC	86	98	112	138	108[a]	$Y=0.1105^{**}x+85.05$	0.99
After planting	SNC	19	35	59	87	50[b]	$Y=0.1434^{**}x+19.70$	0.99
	SC	77	92	110	161	110[a]	$Y=0.00015^{**}x^2+0.102^{**}x+77.02$	1.00
				Fe-P (mg dm^{-3})				
Before planting	SNC	61	69	77	86	73[b]	$Y=0.0382^{**}x+99.12$	0.89
	SC	135	136	148	146	141[a]		
After planting	SNC	57	84	102	112	89[b]	$Y=0.0993^{**}x+100.52$	0.95
	SC	134	149	155	179	154[a]		
				Ca-P (mg dm^{-3})				
Before planting	SNC	7	61	54	62	46[a]	$Y=-0.0004^{**}x^2+0.28^{**}x+20.87$	0.63
	SC	20	77	46	66	52[a]		
After planting	SNC	13	56	55	72	49[a]	$Y=-0.0002^{**}x^2+0.204^{**}x+24.91$	0.84
	SC	29	58	49	68	51[a]		
				P-Mehlich-1 (mg dm^{-3})				
Before planting	SNC	1	22	70	128	55[b]	$Y=0.2738^{**}x-2.30$	0.99
	SC	10	40	80	170	75[a]	$Y=0.00019^{**}x^2+0.2456^{**}x+9.41$	0.99
After planting	SNC	1	18	69	110	49[b]	$Y=0.2549^{**}x+3.35$	0.98
	SC	10	34	77	137	64[a]		
				P-Resin (mg dm^{-3})				
Before planting	SNC	1	39	84	120	61[b]	$Y=-0.0003^{**}x^2+0.395^{**}x+16.28$	0.99
	SC	32	78	105	154	92[a]		
After planting	SNC	5	31	70	98	51[b]	$Y=-0.00025^{**}x^2+0.322^{**}x+2.54$	0.98
	SC	29	53	76	116	69[a]	$Y=0.1808^{**}x+30.61$	0.99
				P-Citric acid (mg dm^{-3})				
Before planting	SNC	4	30	76	212	81[b]	$Y=0.00056^{**}x^2+0.163^{**}x+3.80$	0.99
	SC	7	48	112	193	90[a]	$Y=0.393^{**}x+7.50$	0.99
After planting	SNC	7	29	87	203	81[a]	$Y=0.0004^{**}x^2+0.226^{**}x+3.85$	0.99
	SC	9	29	67	182	72[b]	$Y=0.000503^{**}x^2+0.121^{**}x+8.23$	0.99
				P- Olsen (mg dm^{-3})				
Before planting	SNC	3.2	3.8	4.2	3.8	3.8[b]	$Y=00011^{ns}x^2+0.007^{*}x+3.20$	0.99
	SC	13	12	14	16	14[a]	$Y=0.0066^{**}x+12.31$	0.82
After planting	SNC	5	7	9	11	8[b]	$Y=-0.00003^{*}x^2+0.03^{**}x+12.39$	0.99
	SC	20	23	26	26	24[a]		

SNC, Soil not cultivated previously; SC, soil cultivated previously. Means followed by the same letter do not differ significantly from the soil use reports at the level of probability by the F test in each sampling. **Significant at the level of 1% probability by the t test.

keep around 45% of total inorganic phosphate in their compartment, even with the application of increased doses of reactive phosphate. The Ca-P fraction, which initially presented the lowest percent participation (10%), became 40% of total inorganic phosphorus in the non-cultivated soil and 27% in the previously cultivated soil

Table 3. Shoot dry matter, grain yield and root dry bean grown in Oxisol not cultivated previously (SNC) and Oxisol cultivated previously (SC) subject to four doses of reactive phosphate Arad.

Historic	Doses of P (mg dm^{-3})					Equations	R^2
	0	120	240	480	Mean		
			Shoot dry matter (g pot^{-1})				
SNC	0.2	3.3	4.6	6.2	3.6^b	Y=0.0047*x+4.08	0.73
SC	6.8	6.6	7.2	5.7	6.6^a		
			Grain yield (g pot^{-1})				
SNC	2.3	7.2	9.1	12.2	7.7^b	Y=0.0193** x+3.64	0.91
SC	12.5	12.2	13.0	11.6	12.4^a	Y=-0.0017^{ns}x+12.70	0.32
			Root dry (g pot^{-1})				
SNC	1.4	2.0	2.3	2.6	2.0^a	Y=0.0013*x+1.76	0.90
SC	1.9	2.0	2.1	2.2	2.0^a		

Means followed by the same letter do not differ significantly from the soil use reports at the level of probability by the F test in each sampling. **Significant at the level of 1% probability by the t test.

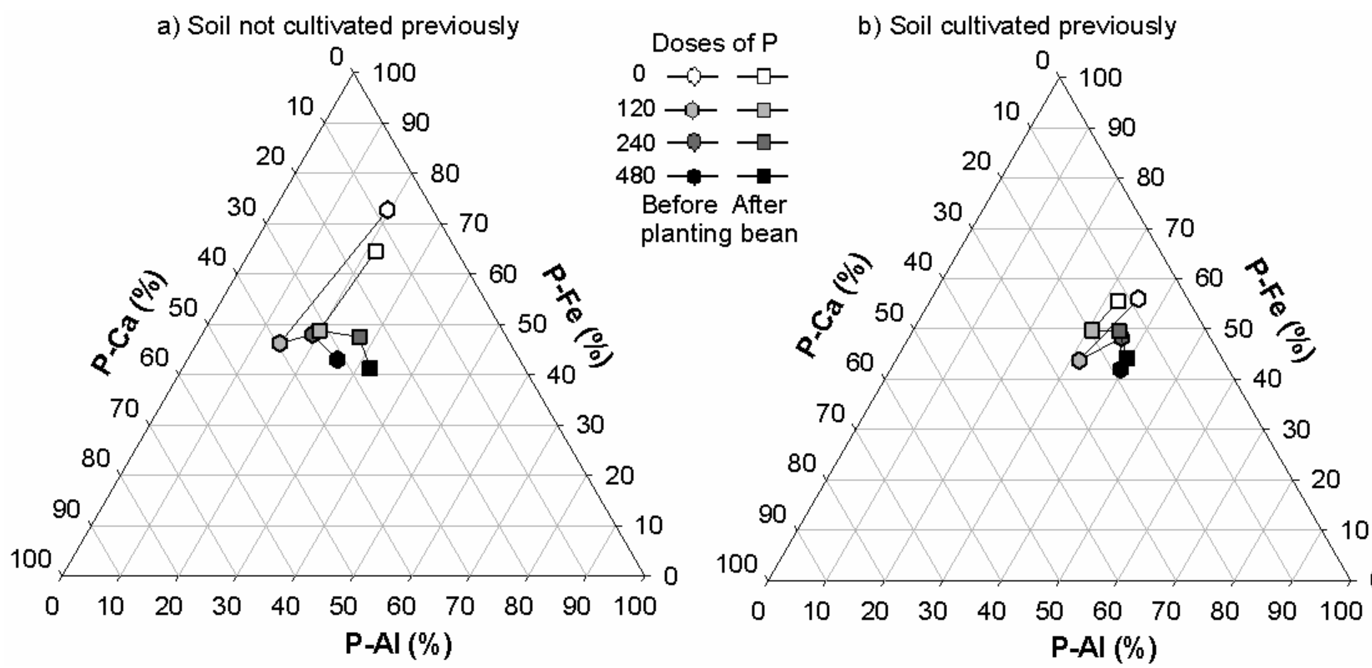

Figure 1. Percent values of Al-P, Fe-P and Ca-P in relation to total inorganic phosphorus (∑ Al-P; Fe-P; Ca-P) in the non-cultivated DRL (Oxisol) (a) and in the DRL cultivated for ten years in no-tillage system (b) both before and after the planting bean.

after the addition of 120 mg dm^{-3} P. This less percent variation of Ca-P, in the soil with cropping report, points out increased transfer of phosphorus from the compartment Ca-P to other fractions. On the other hand, the application of increased amounts of P (240 and 480 mg dm^{-3} of P) promoted only a small variation in relation to the dose 120 mg dm^{-3} of P. The percent Ca-P kept between 25 to 35% in the soil not cultivated previously and between 15 to 20% in the soil cultivated previously. The discontinuity of the trend of percent increase of Ca-P at the highest doses of P applied suggests that plants reached their maximum capacity of draining Ca with the highest doses of reactive phosphate.

The behavior of phosphorus before and after the bean plant cropping allows us to state that the fraction Al-P increases gradually at the expense of the fraction Ca-P, independently of the use report (Figure 1a and b). The percent increase of Al-P is likely associated with the high

Table 4. Correlation between the inorganic fraction of phosphorus, P available by different methods and parameters of P use by the bean plant on the non-cultivated DRL (Oxisol) and on the one previously cultivated, before and after cultivation.

Historic		Al-P	Fe-P	Ca-P	Al-P	Fe-P	Ca-P
		Soil not cultivated previously			Soil cultivated previously		
Mehlich-1	Before	0.97**	0.92**	0.60*	0.97**	0.33	0.40
	After	0.98**	0.88**	0.71**	0.97**	0.76**	0.65**
Resin	Before	0.92**	0.94**	0.71**	0.94**	0.38	0.52*
	After	0.97**	0.93**	0.81**	0.95**	0.76**	0.68**
Citric acid	Before	0.98**	0.87**	0.54*	0.96**	0.35	0.40
	After	0.97**	0.85**	0.70**	0.97**	0.73**	0.62*
Olsen	Before	0.30	0.42	0.52*	0.71**	0.26	0.06
	After	0.96**	0.90**	0.76**	0.71**	0.54*	0.46
SDMA	Before	0.72**	0.88**	0.63**	0.12	0.15	-0.05
	After	0.83**	0.88**	0.78**	0.21	0.36	0.03
Accumulated P	Before	0.77**	0.82**	0.79**	0.77**	0.38	0.16
	After	0.86**	0.96**	0.83**	0.79**	0.61*	0.49
DMB	Before	0.70**	0.87**	0.61*	0.09	0.20	-0.05
	After	0.81**	0.88**	0.78**	0.15	0.32	-0.08

SDMA, Shoot dry matter accumulated; Accumulated P, phosphorus accumulated till flowering; DMB, dry matter of beans. *Significant at the level of 5% probability by the Student t test **Significant at the level of 1% probability by the Student t test.

contents of gibbsite of DRL which is around 110 g kg^{-1} of soil (Table 1). Those results are also in agreement with the stability equations for Al, Fe and Ca phosphates, reported in Mello and Perez (2009). Those authors state that in acidic soils, it is expected that Ca phosphates applied in soil as fertilizers, increase the P availability in a short term, but with time they convert into Al and Fe-bound forms.

In the soil not cultivated previously, there was a percent increase of the fraction Al-P after the bean plant cropping (Figure 1a), but in the soil of constructed fertility, independently of the dose of P applied, the percent of the fraction Al-P kept between 30 to 40% of the total inorganic P, before and after the bean plant cropping. The variations of the percents of the fractions Al-P, Fe-P and Ca-P in soil cultivated previously are quite lower than in the non-cultivated soil. This shows that there is a percent stabilization point of the phosphorus distribution among the three fractions with the successive cultivations (Figure 1b). Under this aspect, the data obtained in the present study allow us to suggest that the phosphorus partitioning in the constructed fertility soil represents the reference of distribution of the fractions of inorganic P. In the non-cultivated soil, the effects of the doses of phosphate and contact tie act in the sense of reaching such a stability point.

Correlations among the inorganic fraction of P and methods of evaluating P availability

The results of the correlation among the inorganic fractions of P and the evaluation methods of their availability can show that the routine extractants have preference in the extraction of certain forms of phosphorus in relation to the chemical action mechanism of the extractor (Table 4). It can be found that the extractors Mehlich-1, ion exchange resin, citric acid and Olsen presented close relationships with the fraction Al-P in the previously cultivated soil, which shows that fraction is the main responsible for the P availability under this condition. In the non-cultivated soil, the extractors presented the highest correlation coefficients with the fraction Al-P and Fe-P, which suggests that in the first fertilizations, available P is coming mainly from the two fractions. The extractor Mehlich-1 presented higher correlation coefficients with the fractions Al-P and Fe-P than with the fraction Ca-P. Nevertheless, it was expected that the extractors constituted by the acidic solutions presented higher correlation coefficients with the fraction Ca-P, according to result found by Rocha et al. (2005) in which the correlation coefficient between Mehlich-1-extracted P and Ca-P was of r=0.83. On the other hand, Kaleeswari et al. (2007) Also found greater

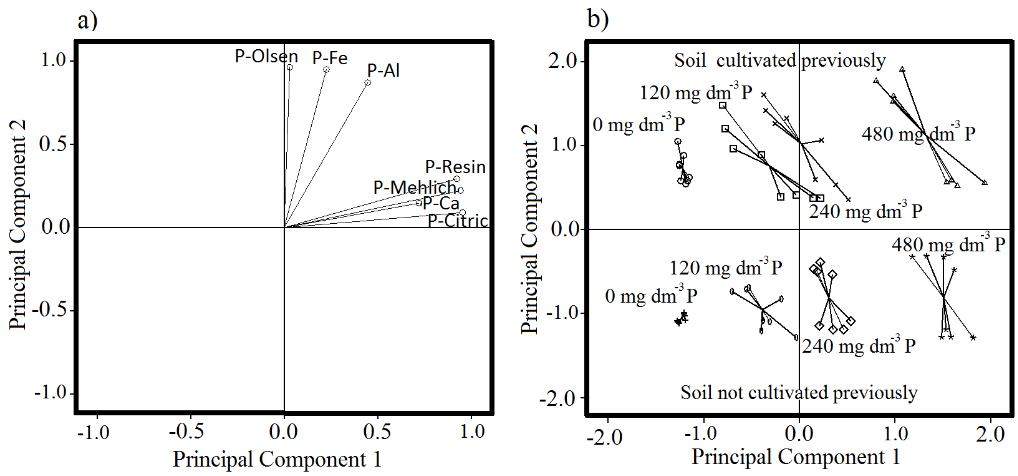

Figure 2. Principal component analysis of the available P contents and inorganic fractions of P in DRL (Oxisol) fertilized with reactive natural phosphate, not cultivated previously and cultivated under no-tillage planting for ten years.

correlation coefficients between the fraction Fe-P and the Mehlich-1-extracted phosphorus contents than between the fraction Ca-P x P-Melhich-1 in India Alfisols.

The correlations of the Ca-P contents with the contents extracted by Mehlich-1, ion exchange resin, citric acid and Olsen increased significantly in the evaluation carried out after the bean plant cropping. This suggests also a role of the plant in the solubilizing of the least soluble phosphates. In the soil not cultivated previously the fractions Al-P. Fe-P and Ca-P presented positive and significant correlations with the shoot dry matter, with the phosphorus accumulated by the bean plant till flowering and with the grain dry matter, in the previously cultivated soil, the shoot dry matter and the grain dry matter correlated with any of the inorganic fractions of P, neither with the contents of extractor-available P. The absence of response of the bean plant to the application of natural reactive phosphate in soil with cropping report, is likely related to the high available P contents before the application of the treatments (Table 1) and points out the possibility of decrease of the doses of P to be applied in areas cultivated in soil which were applied successive phosphate fertilizations for several years. It indicates that Fe-P and Al-P stocked can return to soil solution and provide the nutrient demand by plants.

Principal component analysis of the inorganic fractions of P and evaluation methods of P availability

It is found that the soil samples were grouped together by the effect of the chemical nature of the extractor. It is important to stand out that the groups were not pre-defined, the grouping of the samples occurred in relation to the inorganic forms of P and of the available phosphorus contents evaluated by different methods. The extractors which act through acidic medium and ion exchange resin influenced directly the positive values of principal component 1 (CP1), while the alkaline extractors or Al-P, Fe-P and available P by Olsen influenced the positive values of principal component 2 (CP2) (Figure 2a).

The P contents determined by the Olsen extractor presented the same trend as Al-P and Fe-P because the principle of Olsen method is the release of Fe-and Al-bound P, since at high pH, the ion HCO_3^- acts replacing the adsorbed P in soil and reduces the activity of Ca^{2+} in solution (Silva and Raij, 1999). On the other hand, the extractors Mehlich-1 and citric acid presented the same trend as the fraction Ca-P, because the solubility of Ca phosphates increases with the reduction of pH (Lindsay, 2001).

In CP1, the samples were grouped together in relation to the doses of P applied (Figure 1b), that accounts for 63.38% of the total variance of the P contents. On the other hand, the dispersion of the samples in CP2 (24.86% of the total variance of the data) considered mainly the use report of the areas, its being possible to separate samples of soils cultivated previously and of the soils not cultivated previously. The variables which influenced the most the dispersion of the samples in CP1 (Figure 1b) were Ca-P, P extracted by the extractors Resin, Mehlich-1 and citric acid, it is noticed that the extractors influenced the dispersion of the samples (Figure 1a) in the same direction as the dose of P applied increases (Figure 1b), indicating that the Ca-P of the samples studied has origin in the reactive natural phosphate applied during the experiment and that there was increase of the P availability with the application of the fertilizer.

In CP2, it is noticed that the group of the samples cultivated previously was influenced by the positive values of the factors Al-P, Fe-P and extracted by the Olsen solution, which shows that the alkaline extractors could reveal the presence of P not associated to the doses of phosphate applied in the short term, as Arad reactive phosphate. In this way, the forms of Al-P, Fe-P and Olsen extractor-extracted P were related to the P storage due to the applications previous to the experiment (Figure 2a, b), which allow us to infer that likely the forms Al-P and Fe-P are the forms controllers of storage of P in Dystyrophic Red Latosol.

In general, the fraction Al-P proved sensitive to the effect of the use report and levels of fertilization. In addition, it was the variable best correlated with the availability of phosphorus by different extractors, P absorption and grain yield by the bean plant. It is plausible, therefore, to state that among the inorganic fractions, Al-P is the one which presents greatest liability and should contribute primarily towards the replacement of phosphorus in solution as plant absorption takes place.

Conclusion

Plants that received the same amount of reactive natural phosphate fertilizer at sowing, grown in soil previously cultivated, produce more beans than plants grown in soil not previously cultivated. The condition which seems to be the one of greatest stability to the partitioning of the fractions of inorganic phosphorus in Dystrophic Red Latosol (Oxisol) fertilized with reactive natural phosphate is of 45% Fe-P, 40% Al-P and 15% Ca-P. Available phosphorus content of Oxisol determined by alkaline extraction, Olsen Method, was closely related to levels of Al-P and Fe-P. On other hand, the concentrations determined by extracting acids (Mehlich-1 and citric acid) were more related to the Ca-P fraction.

REFERENCES

Alleoni LR, Mello JWV, Rocha WSD (2009 Electrochemical adsorption and ion exchange in soil. In: MELO VF, ALLEONI LR (Ed.). Soil chemistry and mineralogy. Viçosa, MG: SBCS, 2009, pp. 152-249.

Braga JM, De Felipo BV (1974). Spectrophotometric determination of phosphorus in soil and plant extracts. Rev Ceres 113: 73-85.

Chang SC, Jackson MI (1957). Fractionation of soil phosphorus. Soil Sci. 84:133-144.

Dyer B (1894). On the analytical determination of probable available mineral plant food in soils. Trans. Chem. Soc. 65:115-167.

Ferreira DF (2011). Sisvar: a computer statistical analysis system. Ciênc. Agrotec. 35:1039-1042.

Gatiboni LC, Kaminski J, Rheinheimer DS (2005). Alterations in soil phosphorus forms after successive extractions with Mehlich-1, Mehlich-3 and anion exchange resin methods. R. Bras. Ci. Solo 29:363-371.

Hartwig I, Oliveira AC, Carvalho FIF, Bertani I, Silva JAG, Schmidt Dam, Valerio IP, Maia LC, Fonseca DAR, Reis CES (2007). Associated mechanisms of aluminum tolerance in plants. Semina: Ci. Agrárias 28:219-228.

Hinsinger P (2001). Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. Plant Soil 237:173-195.

Kaleeswari Rk, Indirani P, Saravanapandian Mrl, Prabhakaran K (2007). Evaluation of soil tests for phosphorus in lowland ecosystem. Res. J. Agric. Biol. Sci. 3:581-583.

Li H, Shen J, Zhang F, Clairotte M, Dreven JI, Cadre EL, Hinsinger P (2008). Dynamics of phosphorus fractions in the rhizosphere of common bean (*Phaseolus vulgaris* L.) and durum wheat (Triticum turgidum durum L.) grown in monocropping and intercropping systems. Plant Soil 312:139-150.

Lindsay WL (2001). Chemical equilibria in soils. New Jersey: Blackburn, 2001. P. 449.

Malavolta E, Vitti GC, Oliveira SA (1997). Evaluation of the nutritional state of plants: principles and applications. Piracicaba: Potafos. p.319.

Mehlich A (1953). Determination of P, Ca, Mg, K, Na, and NH_4. North Carolina: NCDA & CS. P. 8.

Mello JWV, Perez DV (2009). Chemical equilibrium of reactions in soil. In: MELO VF, ALLEONI LR (Ed.). Soil chemistry and mineralogy. Viçosa, MG: SBCS, pp. 152-249.

Oliveira Júnior A, Prochnow LI, Klepker D (2008). Agronomic effectiveness of phosphate rock evaluated in soybean crop. Pesq. Agropec. Bras. 43:623-631.

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Washington: USDA, P. 22.

Partelli FL, Busato JG, Vieira HD, Viana AP, Canellas LP (2009). Organic matter quality and phosphorus distribution in soils under organic Conilon coffee. Cienc. Rural 39:2065-2072.

Pavinato PS, Merlin A, Rosolem CA (2009). Phosphorus fractions in Brazilian cerrado soils as affected by tillage. Soil Till. Res. 105:149-155.

Raij BV, Quaggio JA, Cantarella H, Ferreira ME, Lopes AS, Bataglia OC (1987). Soil Analysis for the purpose of fertility. Campinas: Fundação Cargill,p. 170.

Rajan SSS, Watkinson JH, Sinclair AG (1996). Phosphate rocks for direct application to soils. Adv. Agron. 57:77-159.

Resende M, Bahia Filho AFC, Braga JM (1987). Clay mineralogy of Latosols estimated by chemical allocation of total oxides content by H_2SO_4 digestion. R. Bras. Ci. Solo 11:17-23.

Resende AV, Furtini Neto AE, Alves Vmc, Muniz JA, Curi N, Faquin V, Kimpara DI, Santos JZL, Carneiro LF (2006). Phosphorus sources and application methods for maize in soil of the Cerrado region. R. Bras. Ci. Solo 30:453-466.

Rocha AT, Duda GP, Nascimento CWA, Ribeiro MR (2005). Phosphorus fractionation and evaluation of available-P extractors in soils of Fernando de Noronha Island. Rev. Bras. Eng. Agric. Ambient. 9:178-184.

Shen H, Yan X, Zhao M, Zheng S, Wang X (2002). Exudation of organic acids in common bean as related to mobilization of aluminum- and iron-bound phosphates. Environ Exp. Bot. 48:1-9.

Silva FC (Org.) (2009). Chemical analysis Manual of soils, plants and fertilizers. Brasília: Embrapa Technological Information, p.627.

Silva FC, Raij B (1999). Phosphorus availability in soils, determined by different extracting procedures. Pesq. Agropec. Bras. 34:267-288.

Wright AL (2009). Soil phosphorus stocks and distribution in chemical fractions for long-term sugarcane, pasture, turfgrass, and forest systems in Florida. Nutr. Cycl. Agroecosyst. 83:223-231.

Zamuner EC, Picone LI, Echeverria HE (2008). Organic and inorganic phosphorus in Mollisol soil under different tillage practices. Soil Till Res. 89:70-77.