PHOSPHORUS AVAILABILITY IN SOILS AMENDED WITH ORGANIC MATERIALS, ESTIMATED BY THREE CHEMICAL METHODS AND TWO ENZYME ACTIVITIES[1]

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SUMMARY

Phosphorus availability in samples of Aquatibia (Typic xerofluvent) and Hoda (Ultic haploxeralf) soils incubated with increasing amounts of organic materials (barley straw, cowpea plant tops, dairy manure and sewage sludge) was estimated by different chemical methods and by measuring the activity of the enzymes acid phosphatase and phosphodiesterase, at the Department of Soils and Environmental Sciences of the University of California/Riverside, from January to November of 1985. In a greenhouse study, yield of dry matter and P uptake by corn plants cultivated in the soil samples with the same organic materials were measured. Water extraction method correlated significantly with P uptake only when dairy manure and sewage sludge were added to Aquatibia and Hoda soils, respectively. The anion-exchange resin and the Mehlich 1 methods were suitable for measuring the P availability to plants when soils received increasing amounts of organic residues, as in both cases this variable was highly correlated with the yield of dry matter and the amount of P uptaken. The high amounts of P extracted by the anion-exchange resin procedure from the soil with high P sorption capacity indicated that this method not only took into account the intensity factor but also gave a better estimate of the capacity factor. Soil phosphodiesterase activity revealed to be a good index for estimating the P availability to the plant when both soils were amended with cowpea plant tops and dairy manure.

Index terms: phosphorus availability, chemical extraction methods, enzime activity, sewage sludge, organic fertilizers, maize.

RESUMO: *DISPONIBILIDADE DE FÓSFORO ESTIMADA POR TRÊS MÉTODOS QUÍMICOS E PELA ATIVIDADE DE DUAS ENZIMAS EM SOLOS QUE RECEBERAM INCORPORAÇÃO DE MATERIAIS ORGÂNICOS*

A disponibilidade de fósforo em amostras dos solos Aquatibia (solo aluvial) e Hoda (podzólico vermelho-amarelo eutrófico), incubados com quantidades crescentes de materiais

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orgânicos (palha de cevada, parte aérea de feijão-caupi, esterco de curral e lodo de esgoto), foi estimada por três métodos químicos e pela atividade das enzimas fosfatase ácida e fosfodiesterase, no Departamento de Ciências do Solo e Ambientais da Universidade da Califórnia / Riverside, de janeiro a novembro de 1985. Em estudo em casa de vegetação, a produção de matéria seca e a quantidade de P absorvida pela parte aérea de plantas de milho cultivadas nos solos que receberam os mesmos materiais orgânicos foram determinadas. A disponibilidade de P medida pela extração com água correlacionou-se, significativamente, apenas quando o esterco de curral e o lodo de esgoto foram adicionados aos solos Aquatibia e Hoda, respectivamente. A resina de troca aniônica e o Mehlich 1 foram os métodos mais indicados para determinar a disponibilidade de P para o milho quando os solos receberam quantidades crescentes dos materiais orgânicos. As altas quantidades de P extraídas pela resina de troca aniônica do solo com alta capacidade de adsorção de P indicaram que esse método foi o que melhor considerou os fatores intensidade e capacidade do solo. A atividade da enzima fosfodiesterase do solo revelou ser um bom índice para a determinação do P disponível para o milho, quando os solos receberam a adição do feijão-caupi e do esterco de curral.

Termos de indexação: disponibilidade de fósforo, métodos químicos de extração, atividade enzimática, lodo de esgoto, adubação orgânica, milho.

INTRODUCTION

Soil testing procedures have been used, with varying degrees of success, to determine the phosphorus status of soils and to assist in making fertilizer recomendations. The quantities and origin of P removed by the many extraction procedures used for soil testing vary widely, as a result of the properties of the extractant and experimental procedures (Luscombe et al., 1979). Weak reagents, such as water and neutral salts, reflect the intensity of the soil P. Other reagents, such as strongly acid or alkaline solutions, extract large amounts of P and give predominantly quantity measurements. Between these extremes, there is a range of conventional methods of varying extracting power, such as the extraction by anion exchange resins, which may give a composite index of quantity and intensity (Williams & Knight, 1963).

Since the organic P pool in the soil may contribute significantly to the P nutrition of the crop during the season (Van Diest & Black, 1959), the correlation between phosphatase activity and microbial activity could be used to estimate the contribution of the soil organic pool to the P supply for the plant. Correlations between phosphatase activity and P availability have been measured with contradictory results. Harrison (1982) observed a positive relationship between P availability in the rhizosphere and phosphatase activity, while more recently, Nahas et al. (1994) found no correlation between acid phosphatase and available or organic P. However, Thien & Myers (1992) suggested that to realistically evaluate the availability of organic P to plants, it is necessary to measure the P readily mineralizable by soil microbes and extracellular phosphatases.

The research reported here was carried out with the objective of evaluating the suitability of three chemical methods and two enzime activities in measuring P availability to plants when soils are amended with different organic materials.

MATERIAL AND METHODS

Information about the chemical and physical properties of the soils, the composition of the organic materials, the treatments and the laboratory procedure used in this experiment are shown in Berton & Pratt (1997). After incubation, phosphorus availability indexes were determined by the following methods: extraction with water (Olsen & Sommers, 1982), Mehlich 1 (Nelson et al., 1953) and anion-exchange resin (Sibbesen, 1978); availability was also estimated by measuring the activity of two enzymes, acid phosphatase (Eivazi & Tabatabai, 1977) and phosphodiesterase (Browman & Tabatabai, 1978).

The procedure for the greenhouse evaluation of these methods is also described in Berton & Pratt (1997), but in the present study the soil samples received no addition of inorganic P. Treatment effects were evaluated by means of analysis of variance (F test), whereas the means from the organic sources within each dose were compared by the Duncan's test at the level of 5%. Linear and curvelinear regressions were conducted according to Snedecor & Cochran (1980).

RESULTS AND DISCUSSION

Availability of P in the organic materials

Data for dry matter yields and P uptake by corn plants grown on the Aquatibia and Hoda soils are shown in Tables 1 and 2. Irrespectively to the organic material added, both yield of dry matter and P uptake were lower for the Hoda soil than the Aquatibia, presumably because of the higher P adsorption capacity of the former, as observed by Berton & Pratt (1997).

Table 1. Effect of four organic amendments on the yield of dry matter and P uptaken by corn plants grown on the Aquatibia soil

Dose applied	Organic amendment		
	ST[1]	CP[1]	DA[1]
	Yield of dry matter (g pot^{-1})		
0	7a[2]	7a	7a
4	10c	31b	42a
8	10b	54a	54a
12	8b	54a	55a
	P uptaken (mg pot^{-1})		
0	10.1a	10.1a	10.1a
4	15.2b	31.0a	43.3a
8	15.4b	69.2a	75.1a
12	14.2b	87.1a	92.4a

(1) ST: barley straw; CP: cowpea plant tops; DA: dairy manure. (2) In each line, numbers followed by the same letter are not significantly different at the 0.05 level according to Duncan's test. CV% for yield of dry matter = 15.59. CV% for P uptaken = 21.38.

Table 2. Effect of four organic amendments on the yield of dry matter and P uptaken by corn plants grown on the Hoda soil

Dose applied	Organic amendment			
	ST[1]	CP[1]	DA[1]	SS[1]
	Yield of dry matter (g pot^{-1})			
0	2.6[2]	2.6a	2.6a	2.6a
4	3.2b	3.5b	3.3b	12.7a
8	3.3c	4.8b	4.5b	43.3a
12	2.9c	6.1b	7.0b	46.4a
16	3.3d	8.1c	10.7b	48.1a
	P uptaken (mg pot^{-1})			
0	1.9a	1.9a	1.9a	1.9a
4	2.5b	2.7b	2.7b	14.2a
8	2.4c	4.2b	4.1b	48.7a
12	2.2d	5.3c	7.2b	62.9a
16	2.5d	8.7c	11.9b	75.6a

(1) ST: barley straw; CP: cowpea plant tops; DA: dairy manure; SS: sewage sludge. (2) In each line, numbers followed by the same letter are not significantly different at the 0.05 level according to Duncan's test.
CV% for yield of dry matter = 8.02. CV% for P uptaken = 8.85.

Regression analysis (Table 3) showed that the addition of barley straw did not affect the yield of dry matter or the P availability in both soils, probably as a result of its low P concentration and wide C:P ratio, as suggested by Fuller et al. (1956). In the Aquatibia soil, yields closed to the maximum calculated by regression analysis, were obtained by adding 8 g kg^{-1} of cowpea plant tops and dairy manure; however, absorption of P was linear up to the highest dose. The incorporation of cowpea plant tops, dairy manure and sewage sludge into the Hoda soil increased both yield of dry matter and the amount of P uptaken by the corn; hence, the results suggest that these organic materials are effective sources of P to plants. Part of the effectiveness of the cowpea treatment can be explained by the high percentage of water soluble P (74%) in this material and its high decomposition rate in the soil. Compared with the other treatments, yield of dry matter and P uptaken by corn plants were significantly higher when Hoda soil was treated with sewage sludge. This greater response for sewage sludge application was probably due to its higher P content compared with the other organic materials and its readily availability of this nutrient to plants (McCoy et al. 1986).

P availability estimated by chemical methods

Different amounts of P were extracted by water, Mehlich 1 and resin methods (Figure 1), suggesting that different forms of P were dissolved to varying degrees by the extractants, as reported by Luscombe et al. (1979). Amounts of P extracted from the Aquatibia soil were higher than those extracted from the Hoda soil, which reflect the high P sorption capacity of the latter. Olsen & Watanabe (1970) showed that the P concentration in the water extract decreased linearly with the increase in clay content of the soils. Regression analysis showed that the addition of cowpea plant tops, dairy manure and sewage sludge linearly increased the amount of P extracted by water from the Aquatibia soil, while only the sewage sludge treatment seemed to present a positive effect on the P extracted from the Hoda soil (Table 4 and Figures 1a and 1b), suggesting that this method should be used with caution for soils with high P sorption capacities.

P extracted by using the Mehlich 1 method (Figures 1c and 1d) increased linearly with the amounts of cowpea plant tops and dairy manure applied, while a quadratic effect was observed for sewage sludge treatment on both soils (Table 4). The lower amount of P extracted from the Hoda soil by this extractant was suggested by Kamprath & Watson (1980) to be probably due to neutralization of the acids by the soil, or resorption of extracted P.

Except for barley straw, the amounts of P extracted by the resin increased linearly with the incorporation of all other organic materials (Figures 1e and 1f). The higher amount of P extracted from the Hoda soil by this extractant suggests that this method not only considers the intensity but also gives a better estimation of the capacity factor, as observed by Gunary & Sutton (1967) and Hislop & Cooke (1968).

P availability estimated by enzyme activity

Barley straw treatments significantly increased acid phosphatase activity in both soils (Figure 2 a and b), while the incorporation of sewage sludge, cowpea plant tops and dairy manure presented an inconsistent effect on the enzyme activity, except for the dairy manure treatment in the Aquatibia soil where a negative correlation was observed.

Table 3. Regression equations and determination coefficients obtained for dry matter yield (YM) and P uptake (YP) as a function of the amounts of organic materials added to Aquatibia and Hoda soils (x)

Organic material[(1)]	Aquatibia soil		Hoda soil	
	Equation	r^2	Equation	r^2
		Dry matter		
ST	YM = 7.44 + 0.76x - 0.06x²	0.98	YM = 2.72 + 0.086x - 0.004x²	0.44
CP	YM = 6.19 + 8.42x - 0.36x²	0.98**	YM = 2.20 + 0.35x	0.97*
DA	YM = 7.95 + 10.11x - 0.52x²	0.99**	YM = 1.64 + 0.50x	0.91**
SS	...	...	YM = -0.33 + 6.00x - 0.17x²	0.94**
		P uptake		
ST	YP = 12.1 + 0.26x	0.38	YP = 2.06 + 0.06x - 0.003x²	0.39
CP	YP = 9.38 + 6.67x	0.98**	YP = 1.34 + 0.40x	0.92*
DA	YP = 13.68 + 6.93x	0.98**	YP = 0.67 + 0.61x	0.90**
SS	...	...	YP = -1.30 + 6.29x - 0.087x²	0.97*

(1) ST: straw; CP: cawpea plant tops; DA: dairy manure; SS: sewage sludge.
*; ** significant at 5 and 1% probability level, respectively.

Table 4. Regression equations and determination coefficients obtained for P extracted by water (YW), Mehlich 1 (YM) and resin (YR) methods and for the activity of the enzimes acid phosphatase (YA) and phosphodiesterase (YP), as a function of the amounts of organic materials (x) added to Aquatibia and Hoda soils

Organic material[(1)]	Aquatibia soil		Hoda soil	
	Equation	r^2	Equation	r^2
		P extracted by water		
ST	YW = 0.75 + 0.011x	0.59	YW = 0.24 - 0.04x + 0.002x²	0.91**
CP	YW = -0.35 + 0.76x	0.96**	YW = 0.24 - 0.03x + 0.002x²	0.96**
DA	YW = 0.08 + 0.70x	0.99**	YW = 0.24 - 0.03x + 0.001x²	0.94*
SS	YW = 2.35 + 0.76x	0.93**	YW = 0.22 - 0.02x + 0.005x²	0.99**
		P extracted by Mehlich		
ST	YM = 4.88 - 0.01x + 0.005x²	0.91	YM = 0.43 - 0.007x + 0.001x²	0.88
CP	YM = 2.90 + 2.83x	0.99**	YM = 0.10 + 0.21x	0.93**
DA	YM = 3.34 + 2.62x	0.99**	YM = 0.36 + 0.14x	0.99**
SS	YM = 1.36 + 14.25x + 0.18x²	0.99**	YM = 0.40 + 0.40x + 0.12x²	0.99**
		P extracted by resin		
ST	YR = 9.16 - 0.28x + 0.015x²	0.88	YR = 4.21 - 0.0024x + 0.003x²	0.82
CP	YR = 5.20 + 3.79x	0.99**	YR = 3.30 + 1.30x	0.98**
DA	YR = 6.99 + 3.59x	0.99**	YR = 3.87 + 1.12x	0.99**
SS	YR = 11.40 + 13.89x	0.99**	YR = 1.84 + 9.24x	0.98**
		Activity of acid phosphatase		
ST	YA = 174 + 20x - 0.90x²	0.91**	YA = 180.35 + 14.58x	0.85**
CP	YA = 170 - 2.41x + 0.04x²	0.42	YA = 194.78 + 0.63x	0.22
DA	YA = 169.46 - 2.92x	0.64**	YA = 196.4 + 2.25x	0.90
SS	YA = 155.94 - 0.81x	0.13	YA = 201.8 - 6.11x + 0.36x²	0.94
		Activity of phosphodiesterase		
ST	YP = 6.14 + 1.82x	0.91**	YP = 23.11 + 3.37x - 0.12x²	0.98**
CP	YP = 3.65 + 1.93x	0.98**	YP = 20.54 + 1.05x	0.93**
DA	YP = 3.37 + 4.16x - 0.15x²	0.95**	YP = 21.71 + 1.41x	0.98**
SS	YP = 2.93 + 2.75x - 0.12x²	0.91**	YP = 22.66 + 1.38x - 0.06x²	0.68

(1) ST: straw; CP: cawpea plant tops; DA: dairy manure; SS: sewage sludge.
*; ** significant at 5 and 1% probability level, respectively.

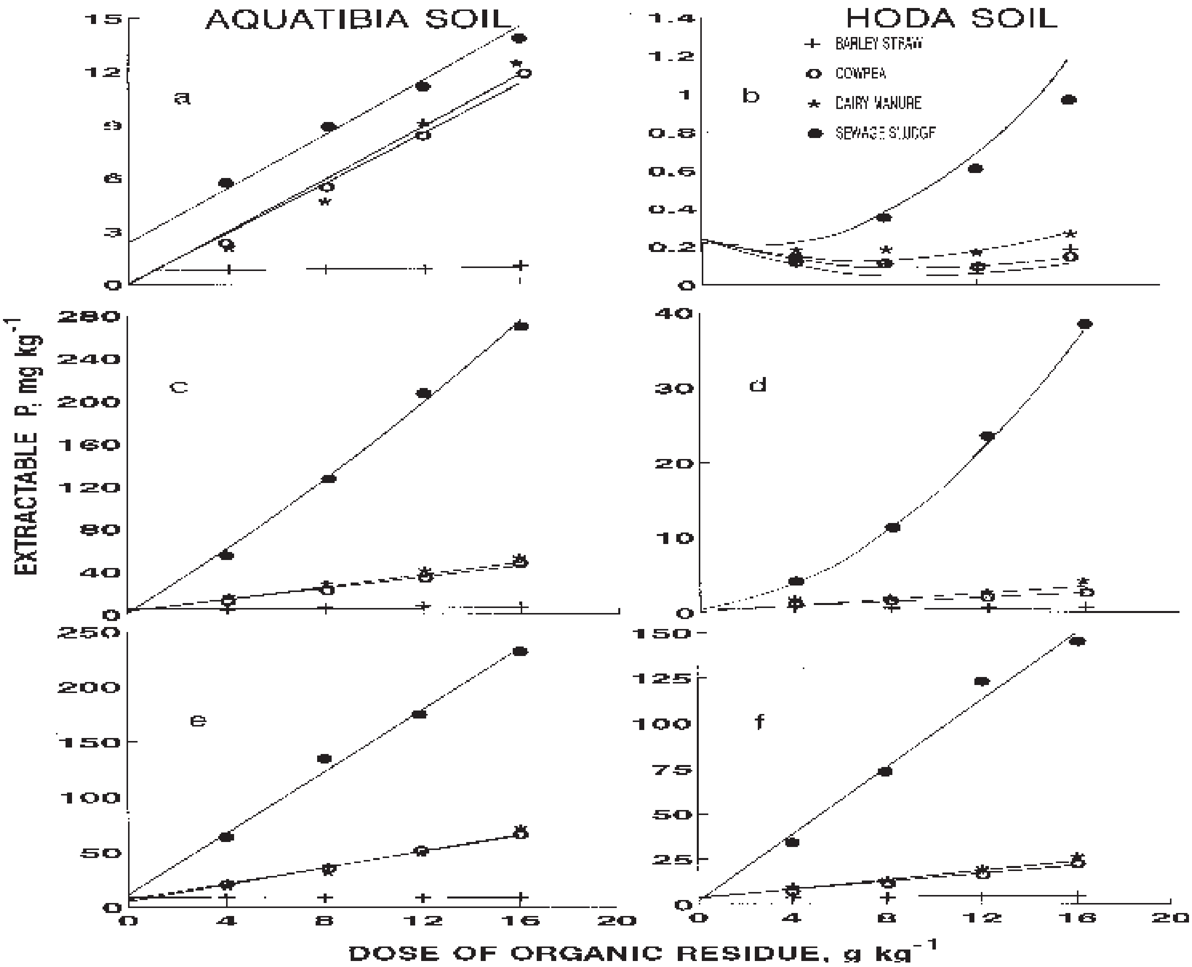

Figure 1. Amounts of phosphorus extracted by the water (a and b), Mehlich 1 (c and d) and resin (e and f) methods, from two soils previously treated with increasing amounts of organic residues and incubated.

In a general view, it seems that the increase in the acid phosphatase activity was inversely proportional to the P content in the organic materials. Probably this was due to the higher release of inorganic P into the soil solution from the cowpea, dairy manure and sewage sludge treatments, which is known to inhibit phosphatase activity (Juma & Tabatabai, 1978).

Activity of the phosphodiesterase enzyme (Figures 2 c and d) was lower than that of the acid phosphatase, which agrees with the results reported by Frankenberger Jr. & Dick (1983). The increase in soil phosphodiesterase activity in all soils due to the addition of the organic materials also seemed to be inversely proportional to the P content of these residues. Along with its high P content, the presence of metals in the sewage sludge treatments could be an important factor in the inhibition of the enzyme activity, as reported by Tyler (1976). Chemical analysis of the organic materials revealed that the sewage sludge contained an average of 53 times more Cu and 27 times more Zn than the other residues.

Linear correlations

Linear correlation coefficients obtained by relating the amounts of P extracted by the chemical methods and the phosphatase activities with the yield of dry matter and the amount of P uptaken by the plants are presented in Table 5. Since the addition of barley straw resulted in no increase in both yield and P uptake, no significant correlation was found for this treatment.

P extracted by the resin procedure showed a high correlation with P uptake and yield of dry matter as also observed by several authors (Bowman et al., 1978; Raij et al., 1986) and was superior to Mehlich 1 method mostly when sewage sludge was applied to the Hoda soil. High correlation between P absorbed by plants and P extracted by dilute solution of strong acids was also reported by Soltanpour et al. (1974). Abbot & Tucker (1973) observed that the extraction of soil P with 0.005 mol L^{-1} HCl gave the best correlation with P uptake when a clay loam soil was fertilized with manure. The higher significance found for the Hoda soil agrees favorably with the results obtained by Cajuste & Kussow (1974) and suggests that this correlation is slightly better in clayey soils than in sandy soils.

The high correlation coefficients observed between P uptake and P extracted by water from the Aquatibia soil amended with dairy manure or from the Hoda soil treated with sewage sludge suggests that this method can be best applied to soils with low buffer

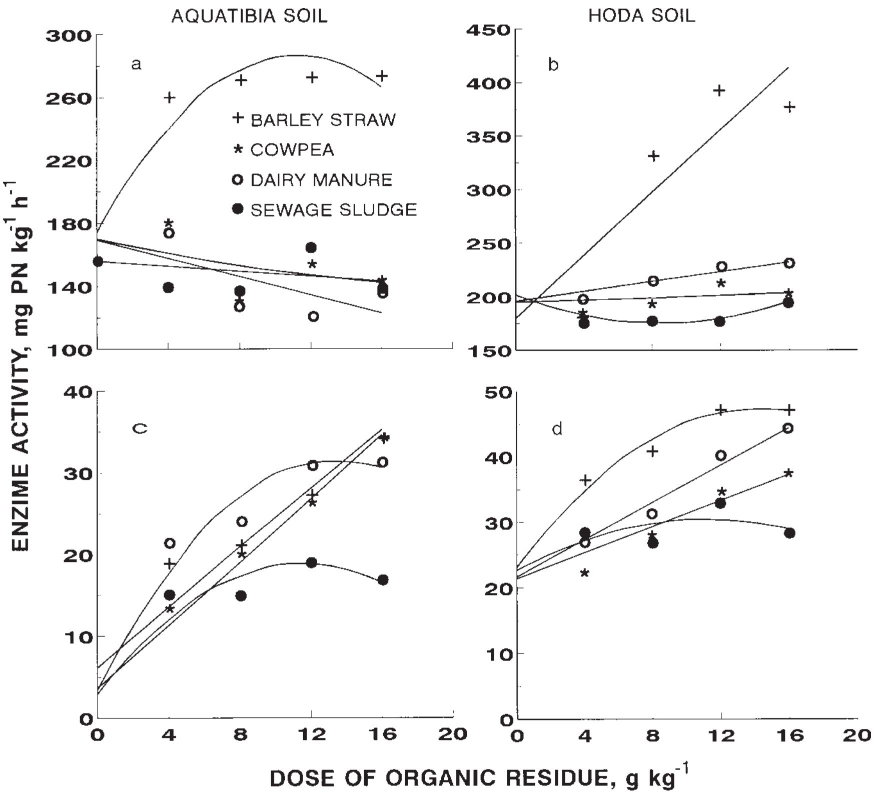

Figure 2. Amounts of *p*-nitrophenol (PN) released by the activity of soil acid phosphatase (a and b) and soil phosphodiesterase (c and d), in two soils previously treated with increasing amounts of organic residues and incubated.

Table 5. Linear correlation coefficients between P availability measured by different methods versus dry matter from tops of corn plants and P uptake by the plants

Plant parameter	Organic amendment(1)	P availability determination method(2)				
		WA	ME	RE	AP	PD
				Aquatibia soil		
Dry matter	ST	0.49	0,16	-0.90	0,78	0,43
	CP	0.84	0,90	0.89	-0,64	0,93
	DA	0.82	0,85	0.86	-0,39	0,96*
P uptake	ST	0.71	0,52	-0.87	0,94	0,76
	CP	0.95	0,98*	0.98*	-0,63	0,99*
	DA	0.96*	0,96*	0.98*	-0,84	0,96*
				Hoda soil		
Dry matter	ST	-0.48	0,06	0.05	0,31	0,64
	CP	0.34	0,99*	0.99*	0,51	0,97*
	DA	0.37	0,96*	0.98*	0,91*	0,96*
	SS	0.76	0,83	0.93*	0,48	0,59
P uptake	ST	-0.49	0,14	0.04	0,23	0,64
	CP	0.42	0,99*	0.99*	0,47	0,94*
	DA	0.35	0,96*	0.96*	0,91*	0,95*
	SS	0.88*	0,93*	0.98*	-0,29	0,60

(1) ST: barley straw; CP: cowpea plant tops; DA: dairy manure; SS: sewage sludge. (2)WA: extraction with water; ME: extraction with Mehlich; RE: extraction with resin; AP: activity of acid phosphatase; PD: activity of phosphodiesterase.
*significant at 5% level.

capacity or to those soils with high P sorption characteristics that had their buffer capacity decreased by the addition of heavy applications of P fertilizer.

Only when the dairy manure treatment was applied to the Hoda soil a significant linear correlation was found between the acid phosphatase activity and both yield of dry matter and P absorbed by the corn. However, phosphodiesterase activity presented a high correlation with yield of dry matter and P uptake for both soils when they were amended with cowpea plant tops and dairy manure. The lack of correlation for the straw treatment probably can be attributed to the inconsistent effect of this material on the enzyme activity, yield and P uptake. Sewage sludge treatments, though increasing the yield and P uptake in the Hoda soil, did not present a significant correlation presumably because its high P and metal contents could have inhibited the activity of the enzyme.

CONCLUSIONS

1. Phosphorus availability measured by the water extration method correlated significantly with P uptake by corn plants when dairy manure and sewage sludge were added to Aquatibia and Hoda soils, respectively.

2. The anion-exchange resin and the Mehlich 1 methods were suitable for measuring the P availability to plants when soils received cowpea plant tops, dairy manure and sewage sludge.

3.High amounts of P were extracted by the anion-exchange resin procedure from the soil with high P sorption capacity, suggesting that this method not only considered the intensity factor but also gave a better estimate of the capacity factor.

4. Soil phosphodiesterase activity revealed to be a good index of the soil P availability to the plant when the Aquatibia soil and the Hoda soil were amended with cowpea plant tops and dairy manure.

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