

ATTRIBUTES OF ACIDITY AND EXCHANGEABLE CATIONS IN OXISOL FERTILIZED BY PHOSPHATE ALKALINE BIOSOLID

ATRIBUTOS DE ACIDEZ E CÁTIOS TROCÁVEIS EM LATOSSOLO FERTILIZADO POR BISSÓLIDO ALCALINIZADO FOSFATADO

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ABSTRACT

Alkaline biosolid enriched by phosphorus (P) increase soil extractable P more than applied alone. It also can exert further effects above soil acidity attributes and exchangeable calcium and magnesium. These facts can contribute to the solution of problems with final destination, attracting farmers to use of adequate quantities of these biosolids by reducing his costs with P fertilization and liming operations. The objective of this work was to evaluate the acidity attributes pH (CaCl_2 0.01 mol dm^{-3}), exchangeable aluminum, potential acidity and exchangeable calcium and magnesium on an acidic Oxisol fertilized with alkaline biosolid phosphated with different levels of phosphorus from three sources after common bean grown under greenhouse condition. An alkaline biosolid was phosphate with 0% P, 0.436% P, 0.872% P and 1.745% P from partially acidulated rock phosphate Alvorada, single superphosphate and triple superphosphate. To establish the treatments was recommended 45.85 kg P ha^{-1} of P from the levels of P added, except from 0% P. Four levels and 3 sources of P generated 12 treatments with 4 replications. Treatments were applied to 2.5 kg dry weight of Oxisol from Arapotí, PR, Brazil, in vases, which was cultivated with 6 common bean plants (cv. IPR Uirapuru). Under these experimental conditions phosphate alkaline biosolid applied in acidic Oxisol provided the largest increases of soil pH, exchangeable calcium and magnesium and decreases in exchangeable aluminum and potential acidity with the level of 0.436% P from the partially acidulated rock phosphate Alvorada and single superphosphate.

Key words: soil pH; potential acidity; exchangeable aluminum; *Phaseolus vulgaris*

RESUMO

Biossólido alcalinizado enriquecido com fósforo (P) aumenta o P extraível mais do que aplicado sozinho. Também pode exercer efeitos adicionais sobre os atributos de acidez e cálcio e magnésio trocáveis do solo. Estes fatos podem contribuir para solução de problemas de destinação final, atraindo produtores à utilização de quantidades adequadas destes biossólidos por reduzir seus custos com adubação e correção de solos. O objetivo deste trabalho foi avaliar os atributos de acidez pH (CaCl_2 0,01 mol dm^{-3}), alumínio trocável, acidez potencial e cálcio e magnésio trocáveis em Latossolo fertilizado com biossólido de esgoto alcalinizado fosfatado com diferentes níveis de fósforo de três fontes após o cultivo de feijoeiro comum em casa de vegetação. Um biossólido alcalinizado foi fosfatado com 0% P, 0,436% P, 0,872% P e 1,745% P de fosfato natural parcialmente acidulado Alvorada, superfosfato simples e superfosfato triplo. Para estabelecer os tratamentos recomendou-se 45,85 kg ha^{-1} de P a partir dos níveis de P adicionado, exceto do nível 0% P. Quatro níveis e 3 fontes de P adicionado geraram 12 tratamentos com 4 repetições. Os tratamentos foram aplicados a 2,5 kg de Latossolo Vermelho Distrófico típico, ácido, em vasos cultivados com 6 plantas de feijoeiro (cv. IPR Uirapuru). Sob estas condições experimentais biossólido de esgoto alcalinizado fosfatado proporcionou os maiores aumentos de pH do solo e cálcio e magnésio trocáveis e diminuições do alumínio trocável e acidez potencial com o nível de 0.436% P de fosfato natural parcialmente acidulado Alvorada e superfosfato simples.

Palavras-chave: pH do solo; acidez potencial; alumínio trocável; *Phaseolus vulgaris*

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INTRODUCTION

The application of sewage alkaline biosolids to agricultural soils can constitute a new sustainable method to eliminate these residues from the urban environment. These alkaline biosolids have in their composition organic matter and macro and micronutrients besides alkaline reaction in soils (Logan e Harrison, 1995). Its alkaline reaction is due to the presence of alkaline materials as calcium and magnesium carbonates (CaCO_3 , MgCO_3) and calcium oxide and hydroxide (CaO , Ca(OH)_2) used in the treatment process (N-Viro Process or single lime and limekiln materials addition). Therefore, to the effect of increasing in the Mehlich-1 soil phosphorus (P) concentration observed by Da Silva et al. (2010), can be added the increasing in the soil pH (Silva et al., 2001; Silva et al., 1998; Sloan e Basta, (1995) and the consequent precipitation of exchangeable aluminum (Al^{3+}) from the soil solution on a non-toxic form and the reduction of the soil acidic potential (Guedes et al., 2006). Increases in exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) (Silva et al., 2001) in soils also have been verified when sewage alkaline biosolids are applied to the soil due to the high total content of these elements when these materials are treated by the alkaline processes (Da Silva et al., 2010).

The main sources of phosphorus (P) used in agricultural systems are single superphosphate and triple superphosphate which have a high calcium concentration in its composition. Single superphosphate is also a sulphur (S) source which occurs in the form of dihydrated calcium sulphate (gypsum). Partially acidulated rock phosphate are considered alternative sources of phosphorus and also have high calcium concentration in its composition according to Novais e Smith (1999). The existence of a high degree of phosphate substitution (PO_4^{3-}) by carbonate (CO_3^{2-}) (high quotient carbonate/phosphate) generate instability into the crystal of the rock phosphate which constitute its non-acidulated portion. For that reason they are more reactive in soils (Korndörfer et al., 1999) and exert further positive effects in the soil acidity attributes and exchangeable calcium and magnesium. Beltrán et al. (1998) applied equal agronomic doses of phosphorus from the reactive Alvorada phosphate rock in the soil, single superphosphate and triple superphosphate. They verified that the soil pH was increased for all phosphorus sources. The increase was more accentuated when the reactive rock phosphate was applied. Vieira et al. (2005) observed increases in the soil pH when they applied an agronomic dose of triple superphosphate. Osztóics et al. (2005) refute these results when they measure the pH of a soil treated with single superphosphate. These same authors verified that the soil pH increases concomitantly the increasing doses of a reactive Algeria rock phosphate. This fact was attributed to its high quo-

tient of carbonate/phosphate (Novais e Smith, 1999) that gives to this rock phosphate a larger reactivity in comparison to the superphosphates.

High quantities of sewage alkaline biosolids have been applied to the soils to supply the crop exigencies by nutrients as nitrogen and phosphorus. This fact can increase soil pH to an exceeding level and generate a prejudicial environment to the plant growth. Phosphorus addition to sewage biosolids from alternative and, or traditional phosphorus sources can be a sustainable practice from the economic and environmental point of view since less quantities of biosolids are incorporated in soils. The lime potential of these alkaline biosolids and of the P sources added can stimulate and attract the farmers to the use of adequate quantities of these biosolids. Additionally, it can reduce the costs with operations related to the liming and phosphate fertilization of the common bean farmers in Parana State, Brazil, who in general, have a familiar and non-capitalized character.

The objective of this work was to evaluate the acidity attributes pH (CaCl_2 0.01 mol dm^{-3}), exchangeable aluminum, potential acidity and exchangeable calcium and magnesium on an acidic Oxisol fertilized by alkaline biosolid phosphated with different levels of phosphorus from three sources after common bean grown under greenhouse condition.

MATERIAL AND METHODS

The experiment was carried out in the greenhouse of the Soil and Agricultural Engineering Department of the Federal University of Parana State, Curitiba/PR/BR (25°48'S, 49°16'15"W) from July to November, 2006.

The arable layer of a silt loam acidic Oxisol (LVDT) from Arapoti, Parana State, Brazil, was sieved on a 2 mm sieve. All the soil analysis were done in the Soil Physics and Soil Fertility Laboratory of the Federal University of Parana State.

The soil presented the following original chemical and physical attributes: sand = 517 g kg^{-1} ; silt loam = 158 g kg^{-1} ; clay = 325 g kg^{-1} (EMBRAPA, 1997); pH CaCl_2 = 3.9; Ca^{2+} = 0.3 $\text{cmol}_c \text{dm}^{-3}$; Mg^{2+} = 0.2 $\text{cmol}_c \text{dm}^{-3}$; K^+ = 0.12 $\text{cmol}_c \text{dm}^{-3}$; Al^{3+} = 1.9 $\text{cmol}_c \text{dm}^{-3}$; H + Al = 11.3 $\text{cmol}_c \text{dm}^{-3}$; CTC (cation exchange capacity) = 11.9 $\text{cmol}_c \text{dm}^{-3}$; V (basis saturation) = 5.2 %; P = 1.0 mg dm^{-3} and organic carbon = 23 g kg^{-1} (Pavan et al., 1992).

A biosolid (from sewage sludge) from the Sewage Treatment Station Belem (SANEPAR) was treated and disinfected by the "Advanced alkaline stabilization with accelerated subsequent drying process" (N-Viro Process) and sieved on a 4 mm sieve. The agronomic characteristics of the alkaline biosolid produced were: moisture = 18%, NC (neutralization capacity = EcaCO_3) = 93,38%;

¹The results of soil extractable phosphorus, accumulated phosphorus, grain and dry mass production by common bean plants in this same oxisol was recently published, in Portuguese language, according to the most adequate formulation for the works extracted from the dissertation of the first author.

RCTN (relative capacity of total neutralization) = 67.54%; pH (CaCl₂ 0.01 mol dm⁻³) = 12.8; N = 4.9 g kg⁻¹; P₂O₅ = 3.47 g kg⁻¹ (or 1.51 g kg⁻¹ of total P); K₂O = 1.0 g kg⁻¹; total S = 1.0 g kg⁻¹; total Ca = 193 g kg⁻¹ (CaO = 269.9 g kg⁻¹); total Mg = 111 g kg⁻¹ (MgO = 182.7 g kg⁻¹); organic carbon = 31.1 g kg⁻¹.

This alkaline biosolid was added by levels

of 0.436% P, 0.872% P and 1.745% P from the partially acidulated rock phosphate Alvorada, single superphosphate and triple superphosphate whose P content and granulometric fractions are shown in the Table 1.

TABLE 1 - Phosphorus concentration and granulometric fraction of partially acidulated rock phosphate Alvorada, single superphosphate, triple superphosphate

SOP ¹	TP ²	³ TTP ₂ O ₅	⁴ P ₂ O ₅ CNA + H ₂ O	⁵ P ₂ O ₅ H ₂ O	Mesh (mm)						
					0.08	0.10	0.25	0.5	1	2	4
	-----g kg ⁻¹ -----				Granulometric fractions (GF g kg ⁻¹) ⁶ -----						
PAP ⁷	84.3	193.4 ⁷	148.2	6.34	65.70	213.10	172.10	180.60	165.60	5.80	0.00
SSP ⁸	64.2	147.4 ⁷	128.9	9.22	0.00	0.00	0.00	0.10	103.10	876.50	20.30
TSP ⁹	195.1	447	441.5	40.04	0.00	0.00	0.00	0.00	2,20	846.70	150.20

¹SOP - source of phosphorus added to alkaline biosolid

²TP - total phosphorus concentration in the source, g kg⁻¹, determined by the method of molybdate blue phosphorus, preceded by nitroperchloric digestion

³TTP₂O₅ - total concentration of P₂O₅ in the source, g kg⁻¹, obtained by calculation based in the total phosphorus concentration

⁴P₂O₅ CNA + H₂O - total concentration of P₂O₅ in the soluble source, g kg⁻¹, by the method of Amonium neutrum citrate + water

⁵P₂O₅ H₂O - soluble phosphorus concentration in water, in g kg⁻¹

⁶GF g kg⁻¹ - quantity of the granulometric fraction retained in the mesh, g kg⁻¹

⁷PAP - Partially acidulated rock phosphate Alvorada

⁸SSP: Single superphosphate

⁹TSP - Triple superphosphate

To establish the treatments (levels of phosphorus added) was used an unique test dose of 45.85 kg ha⁻¹ of P (105 kg ha⁻¹ of P₂O₅ or 23 mg dm⁻³ of P) from the level of 0.436% P, 0.872% P and 1.745% P according to CQFS-SC/RS (2004). A maximum dose of 10500 kg ha⁻¹ dry weight of the mixture P source + sewage alkaline biosolid was obtained when was recommended the test dose from the level of 0.436% P for all sources. Based on this test dose was taken 10500 kg ha⁻¹ of pure sewage alkaline biosolid as specific controls generating the level of 0% P for each source of P added (treatments 1, 5 and 9 on the Table 2).

Four levels and three phosphorus sources originated 12 treatments with 4 replications. Thus, the unique causes of variation were level and source of P added. The mixtures of alkaline biosolid + sources of P to supply 45.85 kg P ha⁻¹, calculated for 1.0 ha (ha) and the quantities of pure alkaline

biosolid on the controls were calculated for vases of 3 dm³ containing 2.5 kg of soil dry weight (Table 2).

Following, the quantities of alkaline biosolid and sources of P were weighted on a precision balance and manual and homogeneously mixed in plastic bags with 6 cm x 12 cm was manually and homogeneously shaken for four times for each treatment.

The treatments were applied and mixed to the soil which was watered till its water retention capacity. Six plants of the IPR Uirapuru variety of common bean were cultivated per vase, under the soil water retention capacity during all the plant cycle.

The nitrogen and potassium fertilization were recommended to 1.0 ha (CQFS-SC/RS, 2004) and calculated for vases and added to the soil surface of vases at the 13 day after seed germination.

²Latossolo Vermelho Distrífico típico according EMBRAPA (1999), collected on a Perennial subtropical forest under secondary succession and never cultivated.

Parana State Sanitation Company.

For more details about the methodology see the dissertation of the first author, defended in the Post-graduating program in Soil Science of the Federal University of Parana State, Brazil.

In English language understand "phosphating" or, simply, "phosphate". In portuguese language understand "fosfatagem".

TABLE 2 - Total doses, per vase, of alkaline biosolid added by phosphorus, amount of phosphorus sources and pure biosolid in the mixture for treatment establishment

Treatment (T)	SPA ¹	LPA ² (%)	TD ³	SQ ⁴	QOS ⁵	DP ⁶
			----- (g vase ⁻¹) -----			
T1	FPA ⁷	0.000	13.125	13.125	0.000	0.000
T2	FPA	0.436	13.125	12.445	0.680	0.057
T3	FPA	0.872	6.563	5.883	0.680	0.057
T4	FPA	1.745	3.281	2.612	0.680	0.057
T5	SSP ⁸	0.000	13.125	13.125	0.000	0.000
T6	SSP	0.436	13.125	12.235	0.890	0.057
T7	SSP	0.872	6.563	5.673	0.890	0.057
T8	SSP	1.745	3.281	2.391	0.890	0.057
T9	TSP ⁹	0.000	13.125	13.125	0.000	0.000
T10	TSP	0.436	13.125	12.831	0.294	0.057
T11	TSP	0.872	6.563	6.269	0.294	0.057
T12	TSP	1.745	3.281	2.987	0.294	0.057

¹SPA: source of phosphorus addition to the alkaline sewage biosolid

²LPA: level of phosphorus addition to alkaline sewage biosolid

³TD: total dose per pot of alkaline sewage biosolid

⁴SQ: quantity of pure alkaline sewage biosolid in the mixture of phosphorus added

⁵QOS: quantity of phosphorus source in the mixture of addition to supply the test dose of 45.85 kg P

⁶DP: dose of phosphorus recommended by 1.0 ha⁻¹ (2000000 mean kg of the arable layer of soil), equivalent to 105 kg ha⁻¹ of P₂O₅ considered a soil density = 1.000 g cm⁻³)

⁷PAP: partially acidulated rock phosphate Alvorada

⁸SSP: single superphosphate

⁹TSP: triple superphosphate

After harvest (95 days after sowing) was collected compound soil samples (from six single samples) to the following analysis: pH (CaCl₂ 0.01 mol dm⁻³), aluminum (Al³⁺) and potential acidity (H + Al) and soil exchangeable calcium (Ca²⁺) and magnesium (Mg²⁺) in the Soil Chemistry and Fertility Laboratory of the Federal University of Parana State.

The experiment was conducted in a completely randomized design 4 by 3. The homogeneity of variance was verified by the Bartlett's test and the means comparison was carried out by the Tukey's test (P<0.05) in the software Mstatc (Michigan State University). Adjustment curves were generated to verify correlations between soil acidity variables, exchangeable calcium and treatments. There were

not data transformations.

RESULTS AND DISCUSSION

The analysis of variance of soil acidity attributes and exchangeable calcium and magnesium are founded in the Table 3.

All the treatments increased the mean values of soil pH for a high significant and isolated interaction between level and source of P added (F<0.01 in the Table 3). The low levels of P added (0% P = specific controls and 0.436% P) were responsible by the larger effects and occasioned increasings of up to 0.5 unit in relation to the original soil pH.

1.0 hectare (ha): 2 x 10⁶ kg average of soil from the soil arable layer. The analysis of soil density showed 1.060 g cm⁻³ which was assumed to be 1.000 g cm⁻³ for purpose of phosphate fertilizer recommendation from the treatments.

TABLE 3 - Analysis of variance of acidity variables and soil exchangeable calcium and magnesium

Source of variation	DF	pH CaCl ₂	H + Al	Al	Ca ²⁺	Mg ²⁺
			----- (cmol _c dm ³) -----			
L	3	0.941 **	16.941 **	4.052 **	6,356 **	2.574 **
S	2	0.056 **	0.806 *	0.126 **	1.802 **	1.681 **
L x S	6	0.016 ^{ns}	0.558 ^{ns}	0.025 ^{ns}	0.387 **	0.266 **
Error	36	0.009	0.239	0.012	0.017	0.046
χ ²		8.03 ^{ns}	13.938 ^{ns}	9.922 ^{ns}	18.59 ^{ns}	14.044 ^{ns}
⁵ CV (%)		2.19	7.05	12.76	8.64	16.49
DMS		0.161	0.831	0.186	0.221	0.364

** : Very significant at level of 99% of probability

* : Significant at level of 95% of probability

ns: non-significant at level of 95% of probability

DF: degrees of freedom

L: level of phosphorus added to sewage alkaline biosolid

S: source of phosphorus added to sewage alkaline biosolid

L x S: interaction between factors level and source of phosphorus added to sewage alkaline biosolid

χ²: qui-square of the Bartlett's test

CV (%): coefficient of variation, in percentage

DMS: minimum significant difference by the Tukey's Test (P<0.05)

The level 0.436% P exerted the larger effect in the soil pH. This fact may be ratified by the results of Da Silva et al. (2010) who used the same methodology of this study and obtained an increasing for soil pH according the decreasing in the levels of P added. It should be noted that these treatments have a lesser quantity of pure alkaline biosolid compared to the specific controls (Table 2), which were composed only by pure alkaline biosolid. Thus, the equivalent increase expected in soil pH caused by the level of 0.436% P compared to those obtained for the control (0% P) was ratified.

The Figure 1 shows the linearity between soil pH increasing according to the decreasing in the levels of P added. This fact may be due to the soil acidity corrective potential of the pure alkaline biosolid present in the mixture related to the treatment 0.436% P. According Oliveira et al. (2002) this fact occurs due to the soil alkaline reaction of the materials used in the treatment process of sewage biosolids (CaCO₃ and CaO, Ca(OH)). The works developed by Melo e Marques (2000), Silva et al. (1998) and Christie et al. (2001) used increasing doses of sewage sludge alone and also are according to the present results.

The sources of P added differ in relation to its chemical composition, solubility and accompanying cation. The PAP was statistically equal to the

TSP in relation to the soil pH. The PAP increased contact with the ground due to its size mash corroborate with the solubilization of components from the non-acidulated portion of this source. Among the components dissolved is the carbonate anion which reacted with the H⁺ in the soil solution and caused the increases in the soil pH values verified (Novais e Smith, 1999; Osztóics et al. 2005). The literature, generally, shows that the TSP decreases the solution pH value around the granule of this P source. More works should be developed to study the effects of this P source above soil pH. A different result was encountered by Beltrán et al. (1998) who applied equal P doses from different sources to the soil and observed superiority for a reactive phosphate rock in comparison to another traditional P sources, among them, the TSP.

All the treatments decreased the Al³⁺ concentration in relation to the initial soil value for an isolated interaction between level and source of P added (F<0.01 in the Table 3). The Figure 2 shows linear increasing for soil Al³⁺ concentration according to the levels of P added. Similarly, the results verified for soil pH, the levels of 0% P e 0.436% P generate the larger reductions, and it was verified values of up to 1.5 cmol_c dm⁻³ lesser in the soil.

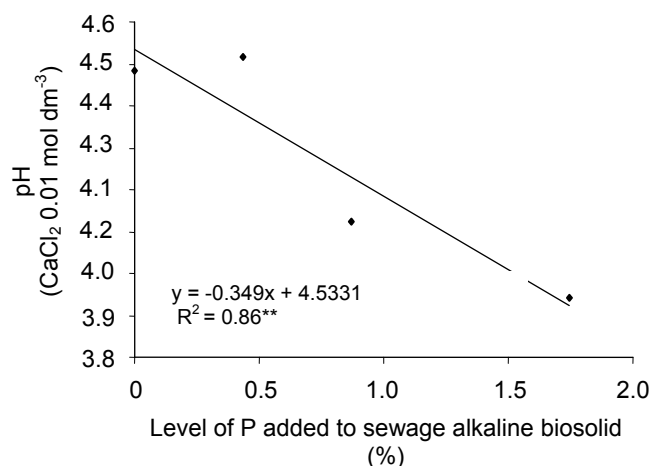


FIGURE 1 - Tendency curve of mean soil pH according the level of P added to sewage alkaline biosolid from three sources (**: significant at the level of 99% probability by the F Test)

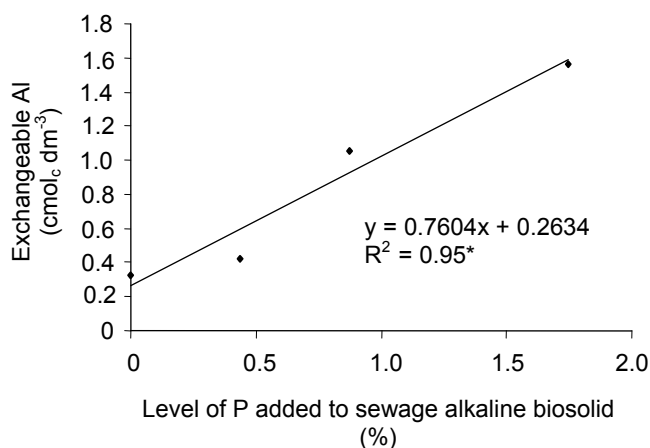


FIGURE 2 - Tendence curve of mean soil exchangeable aluminum according the level of P added to sewage alkaline biosolid from the three sources (*: significant at the level of 95% probability by the F Test)

This observation also must be related to the increasing quantities of the pure alkaline biosolid in the mixtures which increased the soil pH values and, as a consequence, decreased the soil Al³⁺ concentration. This results are the same verified in the work carried out by Da Silva (2010) who obtained increases in the soil pH values with consequent decreases in the Al³⁺ values according to the decreasing in the levels of P added. his fact shows the inverse proportionality between this acidity variables which was ratified by the Figure 3 and the works developed by Sloan e Basta (1995) and Fia et al. (2005) that used increasing doses of sewage sludge also in acidic soils.

All the sources of P added also contributed to the decreasing of the exchangeable Al³⁺ concentration in the soil. This fact may be due, partially, to the Al³⁺ precipitation with the soluble P present in these P sources (Novais e Smith, 1999). Therefore,

numerically, the lesser concentration of exchangeable Al³⁺ was verified for partially acidulated rock phosphate Alvorada (Table 4), which occasioned the larger decrease in relation to the original value. This result, probably, is due to the increase in the soil pH and, consequently, in the values of soil exchangeable Al, that is a well known fact verified in the relevant literature. Da Silva et al. (2010) developed a work using the same methodology and his results confirm those obtained in the present work. Also according to the works developed by Beltrán et al. (1998) and Osztóics et al. (2005) this fact is related to the larger reactivity of the phosphorite present in its non-acidulated portion which, added to the liming potential of the alkaline biosolid present in the mixtures, corroborated to the increasing verified for soil pH with concomitantly decrease in the soil Al³⁺ concentration.

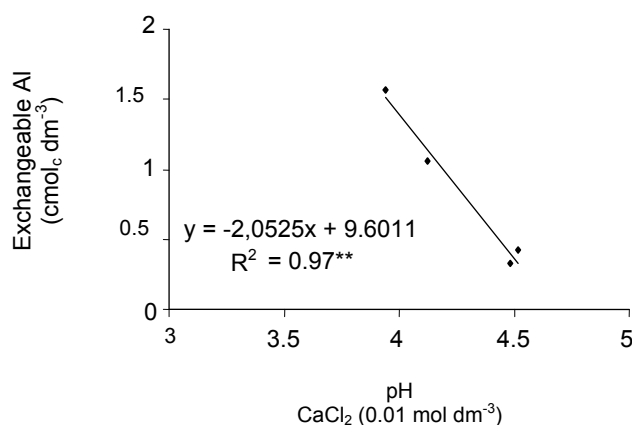


FIGURE 3 - Tendence curve of mean soil exchangeable aluminum according the mean soil pH (**: significant at the level of 99% probability by the F Test)

TABLE 4 - Mean comparison of pH CaCl₂, exchangeable aluminum and potential acidity (H + Al) on an oxisol for sources of phosphorus added to sewage alkaline biosolid.

Source ¹	Mean		
	pH CaCl ₂	Al ³⁺ ----- (cmol _c dm ³) -----	H + Al
PAP ²	4.312 a	0.744 a	6.669 a
SSP ³	4.200 b	0.913 b	7.075 a
TSP ⁴	4.287 a	0.875 b	7.037 a

Note: Means followed by the same word at the vertical not differ statistically by the Tukey's Test the level of probability of 95%

¹Source - source of phosphorus added to sewage alkaline biosolid

²PAP - partially acidulated rock phosphate Alvorada

³SSP - single superphosphate

⁴TSP - triple superphosphate

Similarly to the results verified for soil pH and Al³⁺ the significant and isolated interaction between level (F<0.01) and source (F<0.05) of P added (Table 3) shows that all the treatments, included specific controls (0% P), decrease the soil potential acidity in relation to the initial value.

In the Figure 4 is observed that the controls and the level of 0.436% P exert the larger effects and occasioned a linear decrease in soil potential acidity values (values of up to 5.3 cmol_c dm³). These increasings were verified to the extent that increased the levels of P added. Therefore, it's not happened according to the presence of larger quantities of soluble P, but, due to the decrease in the quantities of sewage alkaline biosolid present in the mixtures of P added (Table 2). This result was also observed by Da Silva et al. (2010) who used similar methodology to this work. Another works as those developed by Sloan e Basta (1995), Silva et al. (1998), Melo e Marques (2000), Fia et al. (2005) and Christie et al. (2001) confirm the effects observed in the present work for soil pH and, conse-

quently, for the values of soil exchangeable Al and potential acidity.

The sources of P added show equivalent effects among each other about the soil potential acidity (Table 4) in relation to the initial soil value. Phosphorus sources as partially acidulated rock phosphate Alvorada can contributes with the increase in the soil pH and, consequently, with the decrease of soil Al³⁺ concentration. Additionally, the exchangeable Al can precipitate with the soluble P present in sources as SSP and TSP (Novais & Smith, 1999).

These effects added to those exerted by the larger quantities of pure alkaline biosolid present in the level of 0.436% P may have corroborated with the linear decrease for soil potential acidity according the increase of the soil pH (Figure 5), and also with the decreasing in the soil potential acidity according the decreasing in the soil exchangeable Al (Figure 6). These results are very similar to those encountered in the work developed by Guedes et al. (2006) who also used increasing doses of sewage

biosolids and Da Silva et al. (2010), Osztóics et al. (2005) and Beltrán et al. (1998).

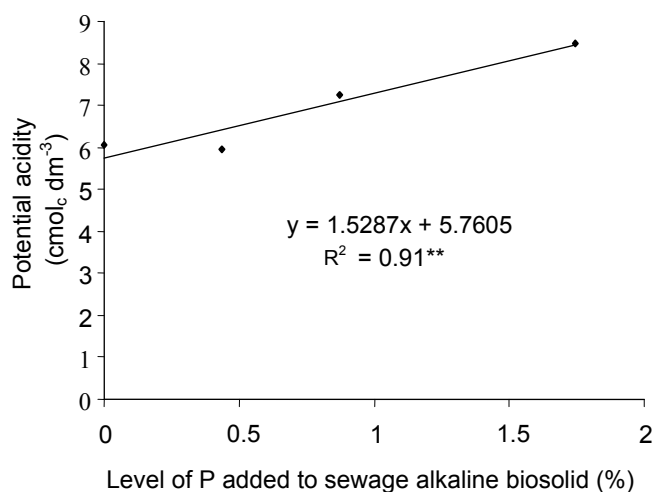


FIGURE 4 - Tendence curve of mean soil potential acidity according the level of P added to sewage alkaline biosolid from the three sources (**: significant at the level of 99% probability by the F Test)

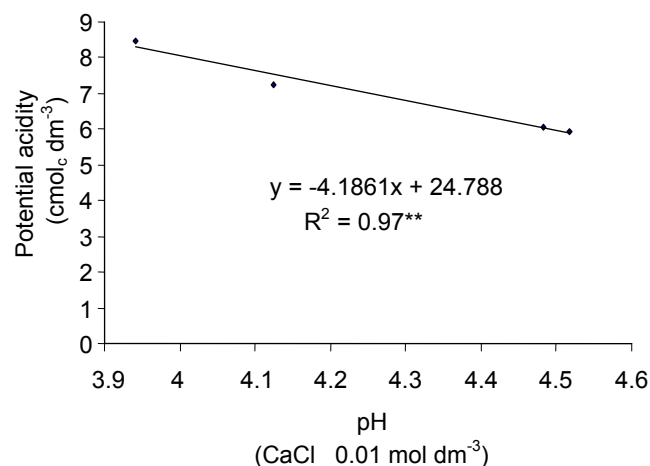


FIGURE 5 - Tendence curve of mean soil potential acidity according the mean soil pH (**: significant at the level of 99% probability by the F Test)

The treatments also increased the soil Ca²⁺ in comparison to the initial soil value for a significant interaction between level and source of P added (F<0.01) as shown in the Table 3. The Figure 7 shows the linearity of the correlation verified between level of P added and soil Ca²⁺ for all sources investigated for P added.

The larger soil exchangeable Ca concentrations were 2.9 cmol_c dm⁻³ and 2.2 cmol_c dm⁻³ obtained, respectively, for the levels 0% P and 0.436% P from the partially acidulated rock phosphate Alvorada. The larger dissolution of those reac-

tive rock phosphate due to the initial soil acidic condition (Novais e Smith, 1999; Korndörfer et al., 1999) added to the decrease in the soil acidity occasioned by the alkaline biosolid may have corroborated to these results observed for partially acidulated rock phosphate Alvorada in relation to the soil exchangeable Ca from the level of 0.436%. It should be emphasised that this treatment occasioned an equivalent Ca²⁺ concentration with the specific control (0% P) which was composed by only pure alkaline biosolid.

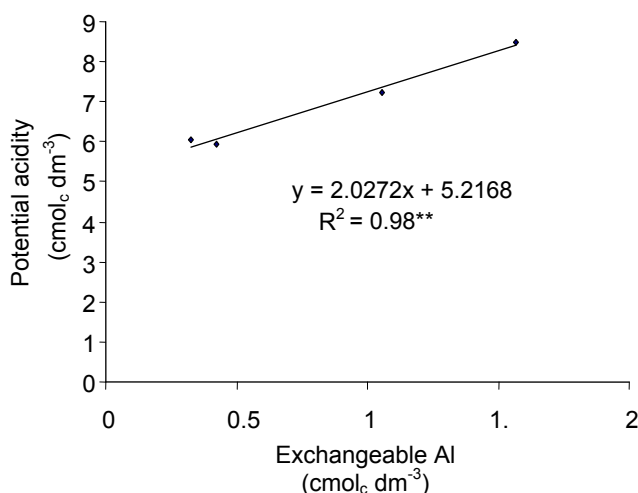


FIGURE 6 - Tendence curve of mean soil potential acidity according the mean soil exchangeable aluminum (**: significant at the level of 99% probability by the F Test)

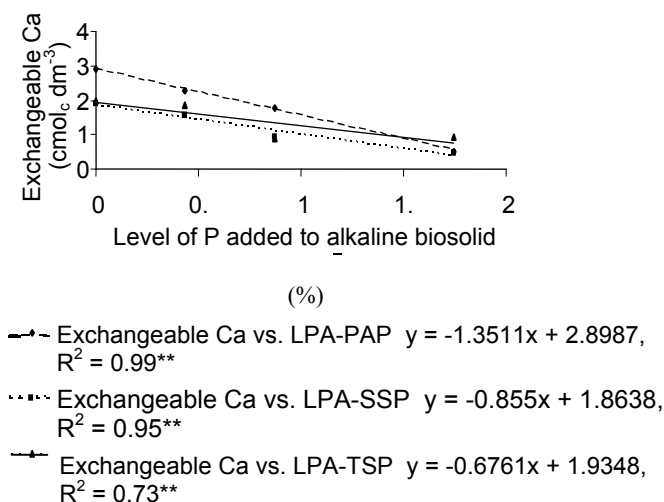


FIGURE 7 - Tendence curve of soil exchangeable calcium according the level of P added to sewage alkaline biosolid from the partially acidulated rock phosphate Alvorada (LPA-PAP), single superphosphate (LPA-SSP) and triple superphosphate (LPA-TSP) (**: significant at the level of 99% probability by the F Test)

These results may be attributed to the high total Ca concentration (193 g kg^{-1}) present in the larger doses of the alkaline biosolid in these treatments (Logan & Harrison, 1995). Additionally, may be due to the high content of total Ca present also in the sources of P added (CQFS-SC/RS, 2004 and Novais e Smith, 1999). The same considerations were made in the discussions held by Da Silva et al. (2010) who used an identical methodology using another oxisol.

All the treatments increase the soil exchangeable Mg^{2+} concentration in relation to the original value for a significant interaction between level and source of P added ($F < 0.01$). Therefore, the larger values of Mg^{2+} were verified also for the treatments referred to the low levels of P added (0% e 0.436% P) from the three sources used, despite of low correlation verified for Mg^{2+} according the

level of P added from the partially acidulated rock phosphate Alvorada (Figure 8). On the contrary, was observed a high correlation between Mg^{2+} and treatments from the sources SSP and TSP.

These results may be due to the larger total Mg concentration present in the doses of pure alkaline biosolid in the low levels of P added (Logan e Harrison, 1995) beyond the small quantity of total Mg in the source SSP (CQFS-SC/RS, 2004) which occasioned an increasing of up to $2.1 \text{ cmol}_c \text{ dm}^{-3}$ in the soil exchangeable Mg from the level 0.436% P.

An identical work was developed by Da Silva et al. (2010) in which the exchangeable Mg concentration of another acidic oxisol was evaluated. These authors show that this variable increase concomitantly decreasing of the levels of P added to the alkaline biosolid. Another authors in the relevant literature applied increasing doses of sewage sludge

in the soil and evaluated the soil Mg^{2+} concentration according the doses applied. Similar result for values of soil Mg^{2+} concentrations were founded by Venâncio Gomes et al. (2005) and increases in the concentration of Mg^{2+} according the increasing of alkaline biosolid doses (Simonete et al., 2003). Also

when Silva et al. (1995) and Silva et al. (2001) applied alkaline biosolids in the presence or not of mineral phosphatic fertilizers they verified a significant participation of Mg^{2+} and in the sum of bases and saturation of soil bases.

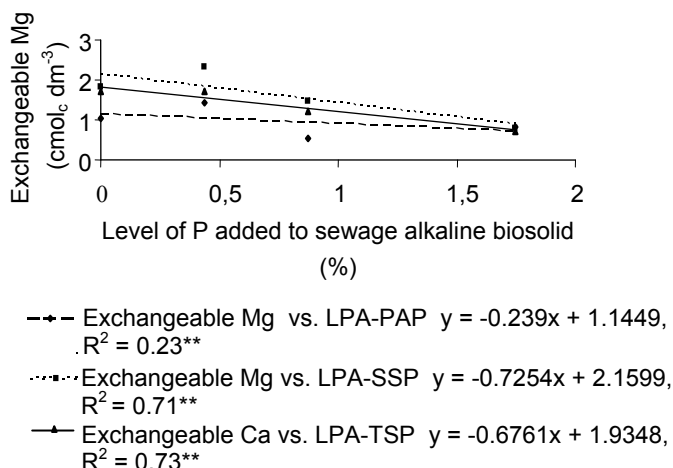


FIGURE 8 - Tendency curve of soil exchangeable magnesium according the level of P added to sewage alkaline biosolid from the partially acidulated rock phosphate Alvorada (LPA-PAP), single superphosphate (LPA-SSP) and triple superphosphate (LPA-TSP) (**: significant at the level of 99% probability by the F Test)

CONCLUSIONS

Under the present experimental conditions phosphate alkaline biosolid applied in acidic Oxisol:

1. Increases its pH ($CaCl_2$ 0.01 mol dm⁻³) and exchangeable calcium and magnesium and decreases its exchangeable aluminum concentration and potential acidity;
2. Provided the largest increases of soil pH, exchangeable calcium and magnesium and decreases

in exchangeable aluminum and potential acidity with the level of 0.436% P from the partially acidulated rock phosphate Alvorada and single superphosphate.

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