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ACIDITY VARIABLES AND EXCHANGEABLE CALCIUM AND MAGNESIUM ON AN OXISOL TREATED WITH PHOSPHATE ALKALINE BIOSOLID

VARIÁVEIS DE ACIDEZ E CÁLCIO E MAGNÉSIO TROCÁVEIS NUM LATOSSOLO TRATADO COM UM BIOSSÓLIDO ALCALINIZADO E FOSFATADO

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ABSTRACT

The alkaline biosolid enriched by phosphorus (P) can increase the soil extractable P[4] and and exert further effects about soil acidity variables and exchangeable calcium and magnesium. This fact can also contributes to the reduction of problems related to its final destination and attract farmers to the use of adequate quantities of these biosolids in agriculture by reduce his costs with soil fertilizers and liming operations. This work aimed to evaluate the acidity variables and exchangeable calcium and magnesium on an Oxisol treated with an alkaline biosolid that received different levels of phosphorus (P) from three sources after common bean grown under greenhouse condition. An alkaline biosolid received 0% P, 0.436% P, 0.872% P and 1.745% P from the partially acidulated rock phosphate Alvorada, single superphosphate and triple superphosphate. To the treatment establishment was recommended 45.85 kg P ha^{-1} from the treatments, except from the 0% P. Four levels and 3 sources of P addition generated 12 treatments with 4 replications. Treatments were applied 2.5 kg dry weight of an Oxisol from Contenda, PR, Brazil, in vases which was cultivated with 6 common bean plants (cv. IPR Uirapuru). After the plant harvest the soil analysis showed increases in the soil pH ($CaCl_2$ 0.01 mol dm^{-3}), exchangeable calcium, magnesium and decreases in aluminum and potential acidity due to the treatments. The assessed variables showed the larger alterations due to the levels 0.436% of P addition in alkaline biosolid from partially acidulated rock phosphate Alvorada and single superphosphate.

Key-words: pH; potential acidity; aluminum; *Phaseolus vulgaris*.

RESUMO

Biossólido de esgoto alcalinizado enriquecido com fósforo (P) pode aumentar o P extraível[5] e afetar adicionalmente as variáveis de acidez e cálcio e magnésio trocáveis do solo. Este fato também pode reduzir problemas com sua destinação final e atrair produtores à utilização de quantidades adequadas destes biossólidos na agricultura por reduzir seus custos com operações de adubação e correção de solos. Este trabalho objetivou avaliar as variáveis de acidez e cálcio e magnésio trocáveis num Latossolo Vermelho-Amarelo Distrófico típico tratado com biossólido alcalinizado que recebeu diferentes níveis de fósforo (P) de três fontes após o cultivo do feijoeiro em casa de vegetação. Um biossólido alcalinizado recebeu 0% P, 0,436% P, 0,872% P e 1,745% P de fosfato natural parcialmente acidulado Alvorada, superfosfato simples e superfosfato triplo. Para o estabelecimento dos tratamentos recomendou-se 45,85 kg P ha^{-1} a partir dos tratamentos, exceto do nível 0% P. Quatro níveis e 3 fontes de adição de P geraram 12 tratamentos com 4 repetições. Os tratamentos foram aplicados em 2,5 kg de solo em vasos cultivados com 6 plantas de feijoeiro (cv. IPR Uirapuru). Após a colheita das plantas as análises mostraram aumento do pH ($CaCl_2$ 0,01 mol dm^{-3}) e cálcio e magnésio trocáveis e diminuição do alumínio trocável e acidez potencial do solo devido aos tratamentos. As variáveis avaliadas mostraram as maiores alterações em função dos níveis 0,436% de adição de P em lodo de esgoto alcalinizado a partir de fosfato natural parcialmente acidulado Alvorada e superfosfato simples.

Palavras-chave: pH; acidez potencial; alumínio; *Phaseolus vulgaris*.

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[4] The results of extractable phosphorus, accumulated phosphorus and productivity of common bean in this same oxisol (Latossolo Vermelho-Amarelo Distrófico típico) are in process of publication, also in english language.
[5] Os resultados de P extraível, P acumulado e produção de feijoeiro neste mesmo Latossolo Vermelho-Amarelo Distrófico típico estão em processo de publicação, também em língua inglesa.

INTRODUCTION

The applicaton of alkaline biosolids from the treatment of sewage sludge to agricultural soils can constitute a sustainable method of elimination of this residue from the urban environment. Alkaline biosolids have organic matter and macro and micronutrients in its composition besides alkaline reaction when applied to soils (Logan & Harrison, 1995). This alkaline reaction is due to the presence of alkaline materials as calcium and magnesium carbonates ($CaCO_3$, $MgCO_3$) and calcium oxide and hidroxide (CaO, $Ca(OH)_2$) used in the treatment process (N-Viro Process or single addition of lime and limekiln materials). Alkaline biosolids increase soil pH (Silva et al., 2001; Silva et al., 1998; Sloan & Basta, 1995) and precipitate exchangeable aluminum (Al^{3+}) from the soil solution on a non-toxic form. Besides, it can reduce the acidic potential of soils (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 into the soils.

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

This work aimed to evaluate the acidity variables pH ($CaCl_2$ 0.01 mol dm^{-3}), exchangeable aluminum, potential acidity and exchangeable calcium and magnesium on an acidic Oxisol treated with an alkaline biosolid that received different levels of phosphorus from the three sources after common bean grown under greenhouse condition.

MATERIAL AND METHODS

The experiment was carried out on the greenhouse of the Department of Soil and Agronomic Engineering of the Federal University of Parana State, Curitiba/PR/BR (25º48"S, 49º16'15"O) from July, 2006 to November, 2006. The arable layer of an acidic Oxisol (LVADt)[6], heavy clayed texture, from Contenda/PR/BR, 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. The soil presented the following original physical attributes: sand = 182 g kg^{-1}; silt loam = 193 g kg^{-1}; clay = 625 g kg^{-1}. The soil chemical characteristics were: pH ($CaCl_2$ 0.01 mol dm^{-3}) = 3.9; Ca^{2+} = 1.0 $cmol_c$ dm^{-3}; Mg^{2+} = 0.6 $cmol_c$ dm^{-3}; K^+ = 0.15 $cmol_c$ dm^{-3}; Al^{3+} = 2.5 $cmol_c$ dm^{-3}; potential acidity (H + Al) = 12.1 $cmol_c$ dm^{-3}; T = 13.8 $cmol_c$ dm^{-3}; V = 12.6 %; P = 1.5 mg dm^{-3} and organic carbon = 31.7 g kg^{-1}.

A biosolid from the sewage sludge originated in the Sewage Treatment Station Belem (SANEPAR)[7] was treated and desinfected by the "*Advanced process alkaline stabilization with accelerated subsequent drying*" (N-Viro Process) and sieved on a 4 mm sieve. Its agronomic characteristics were: umidity = 18%, NC (neutralization capacity = $ECaCO_3$) = 93.38%, RCTN (relative capacity of total neutralization) = 67.54%, pH ($CaCl_2$ 0.01 mol dm^{-3}) = 12.8; N = 4.9 g kg^{-1}, P_2O_5 = 3.47 g kg^{-1} (or 1.51 g total P kg^{-1}), K_2O = 1.0 g kg^{-1}, S = 1.0 g kg^{-1}, total Ca = 193 g kg^{-1}, total Mg = 111 g kg^{-1}, organic carbon = 31.1 g kg^{-1}.

To this alkaline biosolid was added different levels of P: 0.436% (1% P_2O_5); 0.872% (2% P_2O_5) and 1.745% (4% P_2O_5) from partially acidulated rock phosphate Alvorada (84.3 g total P kg^{-1}), single superphosphate (64.2 g total P kg^{-1})

[6]Latossolo Vermelho-Amarelo Distrófico típico (Embrapa, 1999) collected on a Perennial subtropical forest under secondary sucession and never cultivated.
[7]Parana State Sanitation Company

and triple superphosphate (195.1 g total P kg^{-1}).

To establish the treatments (levels of added phosphorus) it was used an unique dose of 45.85 kg P ha^{-1} (105 kg P_2O_5 ha^{-1}) 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 it 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 alkaline biosolid as specific controls generating the level of 0% P for each source of phosphorus addition (treatments 1, 5 and 9 on the Table 1). Four levels and three phosphorus sources originated 12 treatments with 4 replications. Thus the unique causes of variation were level and phosphorus source. The mixtures of alkaline biosolid + P sources to supply 45.85 kg ha^{-1} of P (23 mg dm^{-3} of Pl), calculated for 1.0 ha ([8]) and the quantities of pure alkaline biosolid on the controls were calculated for vessels of 3 dm^3 containing 2.5 kg of soil dry weight. Following, the quantities of biosolid and phosphorus sources were weighted (Table 1) on a precision balance and manual and homogeneously mixed on the plastic bags with 6 cm x 12 cm in the Laboratory of Soil Chemical and Fertility of the Federal University of Parana State.

TABLE 1 - 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] QL[4]	QOS[5] QF[5]	DP[6] 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

[1]SPA: source of phosphorus addition to the alkaline sewage biosolid; [2]LPA: level of phosphorus addition to alkaline sewage bosolid; [3]TD: total dose per pot of alkaline sewage biosolid; [4]SQ: quantity of pure alkaline sewage biosolid in the mixture of phosphorus addition ; [5]QOS: quantity of phosphorus source in the mixture of addition to supply the test dose of 45.85 kg P; [6]DP: dose of phosphorus recommended by 1 ha^{-1} (2000000 mean kg of the arable layer of soil), equivalent to 105 kg ha^{-1} of P_2O_5 considered a soil density = 1.000 g cm^{-3}); [7]PAP: partially acidulated rock phosphate Alvorada; [8]SSP: single superphosphate; [9]TSP: triple superphosphate

The treatments were applied and mixed in the soil that was watered till its field capacity. Six plants of the IPR Uirapuru variety of common bean were cultivated per vase. The nitrogen and potassium fertilization were recommended to 1.0 ha (CQFS-SC/RS, 2004) and calculated for vases. Following, they were added to the soil vases surface at the 13 day after seed germination. After harvest (95 days after sowing) it was collected compound soil samples (from the 6 single samples) to the following analysis: pH ($CaCl_2$ 0.01 mol dm^{-3}), aluminum (Al^{3+}) and potential acidity (H + Al) and exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the Soil Chemical and Fertility Laboratory of the Federal University of Parana State.

The experiment was conducted on a completely randomized design 4 by 3. The homogeneity of variance was verified by the Bartlett test and the means comparison was carried out by the Tukey test (P<0.05) in the software MStatc (Michigan State University). Adjustment curves were generated to verify correlations between soil acidity variables and treatments and exchangeable magnesium and treatments. There were not data transformations.

[8] 1.0 hectare (ha): 2 x 10^6 kg average of soil from the arable layer. Analysis of soil density showed 1.030 g cm^{-3} that was assumed to be 1.000 g cm^{-3} for purpose of phosphate fertilizer recommendation from the treatments.

RESULTS AND DISCUSSION

The results obtained for soil pH ($CaCl_2$ 0.01 mol dm^{-3}) (F<0.05) showed that was significant interaction between level and source of P added according the Figure 1 and Table 2. The values of soil pH were increased for all treatments in relation to the initial values. The lower levels of phosphorus added (0% P = controls and 0.436% P) were superior in comparison to the other treatments. For the controls (0% P) were observed greater increases in the soil pH values because these treatments were made only by pure alkaline biosolid and in a greater quantity than that found in the treatments related to the levels 0.436% P. However, similar results were obtained with the levels 0.436% P for all sources of phosphorus addition (Figure 1). There was an increase of up to 0.7 pH units in comparison to the initial soil pH. The increase of pure alkaline biosolid quantities present in the mixtures refereed to these levels of P added combined with the acidity neutralization capacity of the phosphate materials contributed to the increase verified in the soil pH.

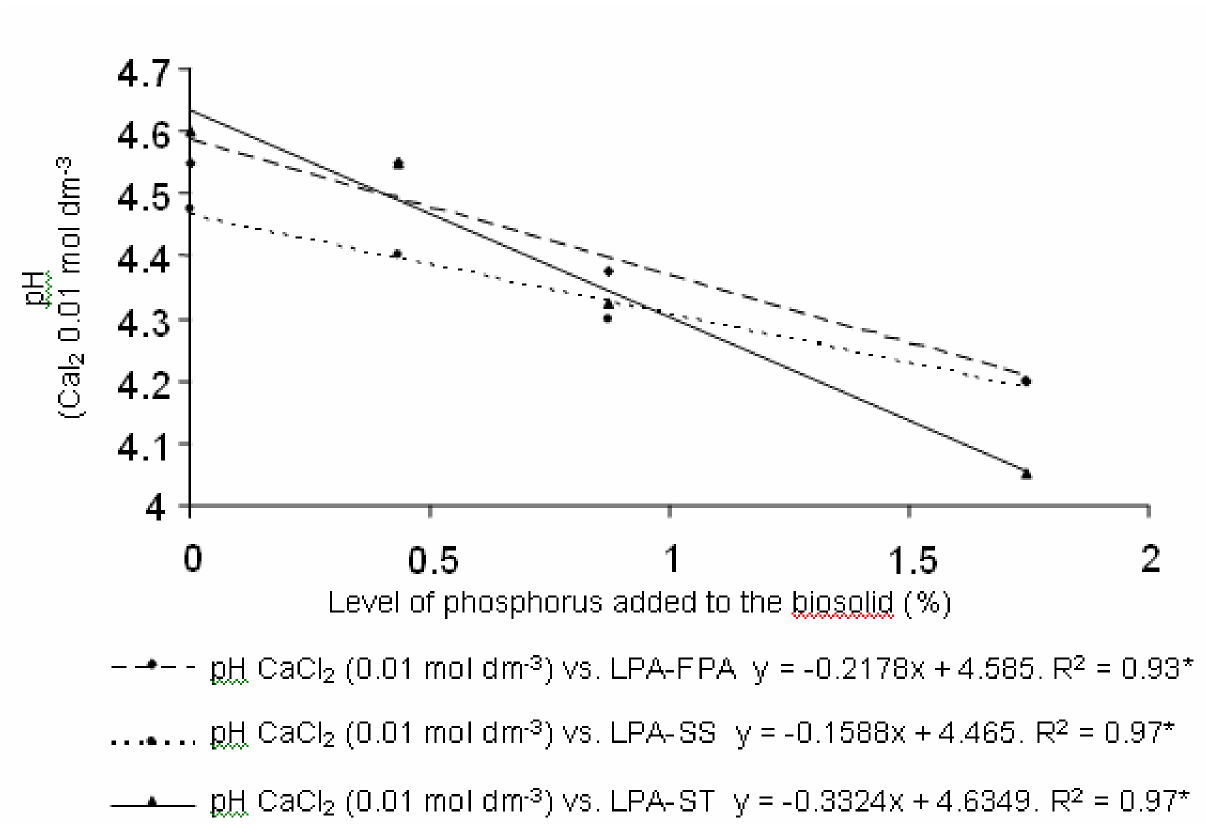

FIGURE 1 - pH $CaCl_2$ in Oxisol according the level of phosphorus added to the alkaline biosolid from the partially acidulated rock phosphate Alvorada (LPA-PAP), single superphosphate (LPA-SSP) and triple superphosphate (LPA-TSP) (F test P<0.05)

TABLE 2 - Means comparison of soil pH $CaCl_2$ according the sources of phosphorus addition

SOP	LPA (%)			
	0	0.436	0.872	1.745
	-----------pH ($CaCl_2$ 0.01 mol dm^{-3})-----------			
PAP	4.600 a	4.550 a	4.325 a	4.050 a
SS	4.475 a	4.400 a	4.300 a	4.200 a
TS	4.550 a	4.550 a	4.375 a	4.200 a
CV (%)	2.020			
DMS	0.152			

Note: Means followed by the same word at the vertical not differ statistically by the Tukey test (P<0.05)
SOP: source of phosphorus added to alkaline sewage biosolid; LPA (%): level of phosphorus added to alkaline sewage biosolid, in percentage; PAP: partially acidulated rock phosphate Alvorada; SSP: single superphosphate; TSP: triple superphosphate; CV (%) = coefficient of variation, in percentage; DMS: least significant difference of the Tukey test

According to Oliveira et al. (2002) this fact can be explained by the soil alkaline reaction of the materials used in the treatment of sewage biosolids ($CaCO_3$ and CaO, Ca(OH)). This result was confirmed by the high negative correlation verified between soil pH and levels of phosphorus addition for all sources (Figure 1). Soil pH remained in a similar values to the original when were increased the levels of phosphorus addition with a consequent reduction of alkaline biosolids quantities present in the mixtures. This fact confirm the fact that the pure alkaline biosolid exert more influence above the soil pH due to its alkaline reaction in acidic soils. These results are according to the works carried out by Sloan & Basta (1995), Melo & Marques (2000), Silva et al. (1998) and Christie et al. (2001) who used different doses of the alkaline biosolids, indicating its efficiency to increase soil pH and, consequently, reduce the soil acidity.

The phosphorus sources showed equivalent between each other about the soil pH as showed in the Table 2. However the literature indicate that different sources can exert influence by different ways upon soil pH. Phosphate rocks are more efficient about the capacity to increase soil pH and, consequently, reduce the soil acidity. This fact must to be due its fine granulometry and the larger reactivity in soils beyond the presence of great quantities of carbonates in these phosphate rocks (Novais & Smith, 1999). The partially acidulated rock phosphate Alvorada has a non-acidulated portion (phosphorite) which is a natural phosphate that has a high reactivity in soils because it has a high quotient carbonate/phosphate.

The factors level and source of P added was individually significant about Al^{3+} ($F<0.01$) as shown in the Figure 2 and Table 3. There was a reduction on the exchangeable concentrations of aluminum (Al^{3+}) for all treatments. However, the controls (0% P) and the levels of 0,436% P led to the larger reductions. This fact must to be due to the larger quantities of pure alkaline biosolid present in these treatments. The Figure 2 confirm these results by the linear increased verified for mean exchangeable Al^{3+} soil concentration verified when increased the level of P addition with the consequent reduction on the biosolid quantities in the mixtures of P added.

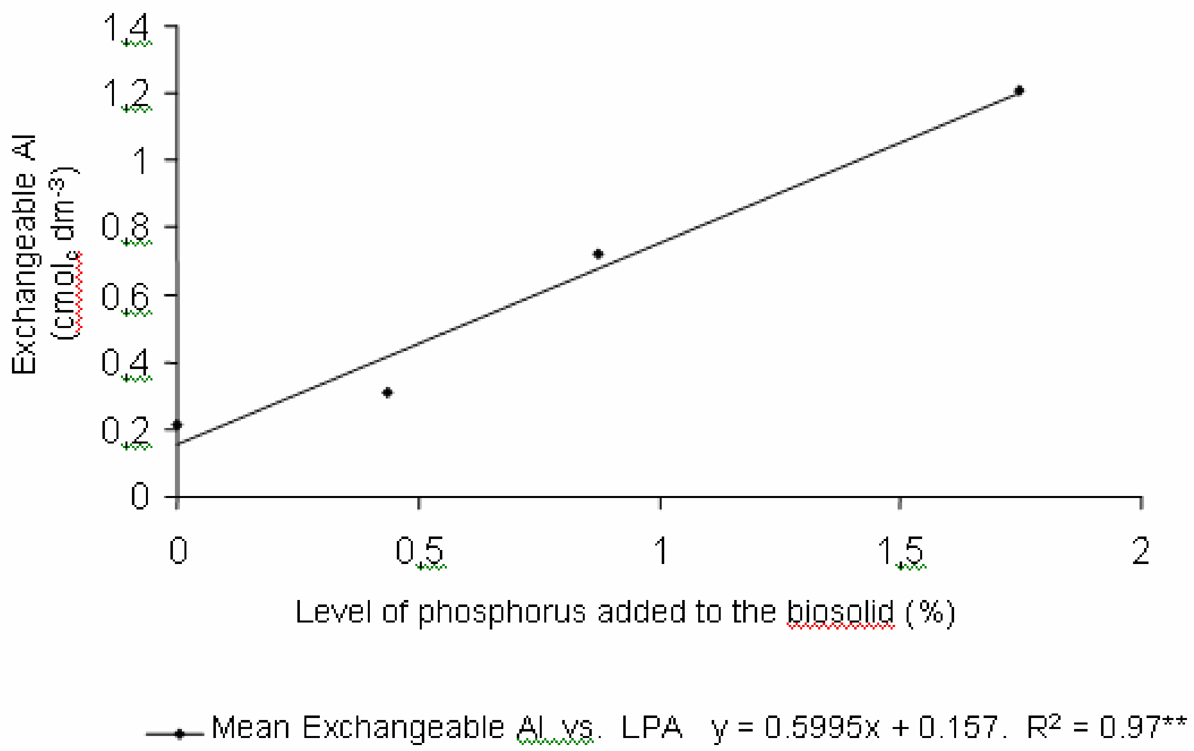

FIGURE 2 - Tendency curve of mean exchangeable aluminum according the level of phosphorus added to the alkaline biosolid from the partially acidulated rock phosphate Alvorada (LPA), single superphosphate (LPA) and triple superphosphate (LPA) (F test $P<0.05$ for an isolated significance for factors level and source of P added to the alkaline biosolid)

TABLE 3 - Means comparison of exchangeable aluminum and potential acidity according the sources of phosphorus addition

SOP	Exchangeable Al	Potential acidity
	------------cmol$_c$ dm^{-3}------------	
FPA	0.588 a	8.620 a
SSP	0.694 a	9.320 a
TSP	0.563 a	8.570 a
CV (%)	13.080	6.630
DMS	0.131	0.995

Note: Means followed by the same word at the vertical not differ estatistically by the Tukey test (P<0.05)
SOP: source of phosphorus added to alkaline biosolid; SOP: source of phosphorus addition; PAP: partially acidulated rock phosphate Alvorada; SSP: single superphosphate; TSP: triple superphosphate; CV (%) = coefficient of variation, in percentage; DMS: least significant difference of the Tukey test

About the phosphorus sources there was a larger reduction of Al^{3+} for the partially acidulated rock phosphate Alvorada and triple superphosphate (Table 3). About the first, this fact must be related to its lime effect exerted by the non-acidulated portion of phosphate rock (phosphorite) upon the soil pH when it was dissolved. About the triple superphosphate, the fact must be due to the part of its soluble phosphorus which must has precipitated with this form of Aluminum in soil due to its acidic condition (Novais & Smith, 1999) and the high concentration of these element, initially. Regarding to the single superphosphate, the effect observed must be due to the presence of dihidrated calcium sulphate (about 40%) that react with the Al^{3+} and decrease its activity and exchangeable concentration in the soil. Same results were encountered in the work developed by Sloan & Basta (1995) who showed that there were linear decreases in Al^{3+} concentrations with high significance when increased doses of N-Viro Soil or limed biosolid were applied to the soil. Similar results were also observed by Fia et al. (2005) when they applied increasing doses of an alkaline biosolid on an acidic Oxisol.

Similarly to the results of Al^{3+} all the treatments decreased the soil potential acidity (F<0.01) for an individually significance for level and source of P addition (Figure 3 and Table 3). The lower levels of phosphorus addition (0% P and 0.436% P) exert the larger effects upon the soil potential acidity reducing it by up to 4.0 cmol$_c$ dm^{-3} in the soil. These results must also be related to the greater amounts of pure alkaline biosolid in these mixtures. This fact is also confirmed by the linear and high significant increase of soil potential acidity due to the increase of levels of phosphorus added (Figure 3) with the consequent reduction of alkaline biosolid quantities in the mixtures (Table 1). The potential acidity remained at values slightly below the initial values with the larger levels of phosphorus addition for all sources (1.745% P). These results were expected confirming the predominant effect of pure alkaline biosolid doses in the mixtures upon the potential acidity due to its capacity to increase soil pH and, consequently, neutralize soil acidity (Logan & Harrison, 1995). Guedes et al. (2006) showed a linear reduction of potential acidity with the increase of pH, which indicates their inverse proportionality, and the decrease of potential acidity with the reduction of Al^{3+} in the soil (Figure 4) which is a well-stablished relashionship.

According to the results verified for soil Al^{3+}, the partially acidulated rock phosphate Alvorada and triple superphosphate was the better sources of phosphorus addition in relation to the soil potential acidity (Table 3). Novais & Smith (1999) indicate that the effect observed for rock phosphate must be due to its small size granules and the lime potential of its non-acidulated part which has high alkaline reactivity and easily decomposable under the acidic conditions initially encountered in this soil (Beltran et al., 1998). These results corroborate with the increases verified in the soil pH which, consequently, reduced the Al^{3+} and the potential acidity, concomitantly. Regarding to the triple superphosphate, a portion of its high content of soluble P must have precipitated with the Al^{3+} from the soil solution (Novais & Smith, 1999). Since occurs reposition of the soil solution Al^{3+} by the solid phase (Al from the potential acidity) the decrease in the acidity potential was verified, as a result. A lesser effect was verified for single superphosphate source. A contrary effect should be observed because the larger gypsum concentrations (Dihidrated calcium sulphate) which is encountered in this phosphorus source (about 40%). The specific literature show that the gypsum react and removes part of the Al^{3+} from the soil solution, reducing its activity and toxic concentrations in soils.

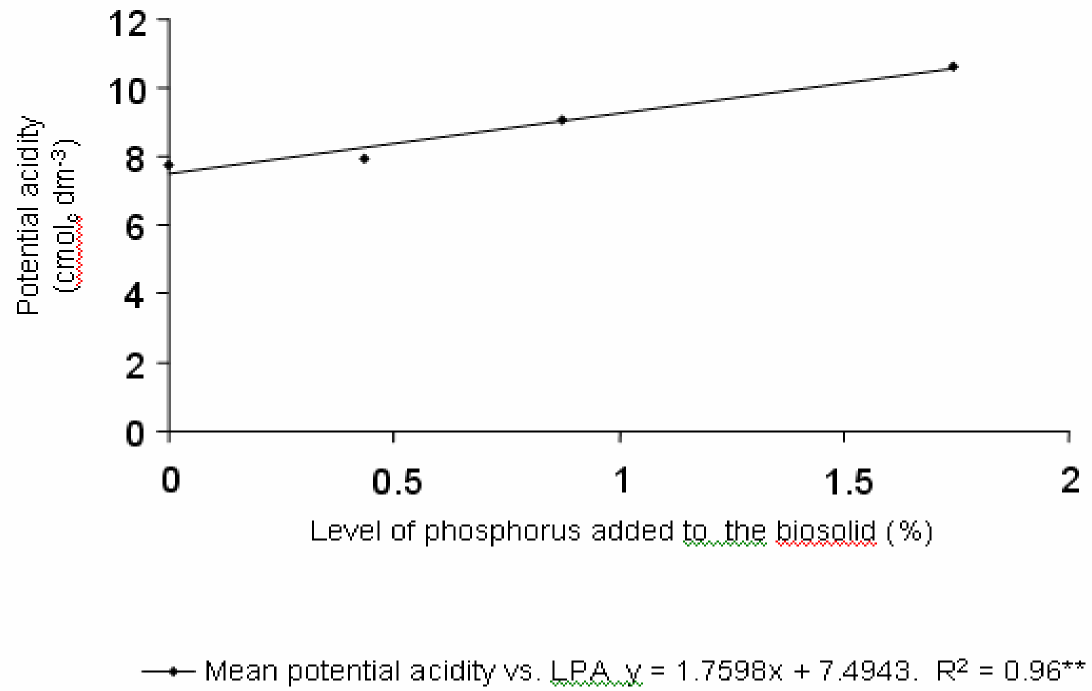

FIGURE 3 - Tendency curve of mean potential acidity according the level of phosphorus added to the alkaline biosolid from the partially acidulated phosphate rock Alvorada (LPA), single superphosphate (LPA) and triple superphosphate (LPA) (F test P<0.05 for an isolated significance for level and source of P addition to the alkaline biosolid)

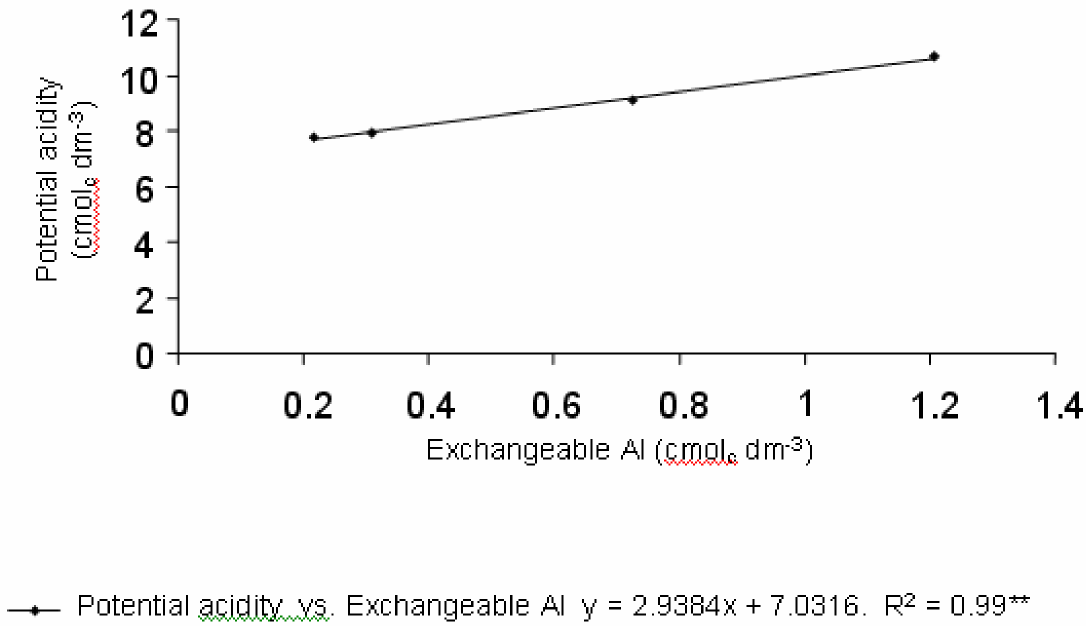

FIGURE 4 - Tendency curve of means of potential acidity according the means of exchangeable aluminum on an Oxisol fertilized with an alkaline biosolid added by four levels of phosphorus addition from the partially acidulated rock phosphate Alvorada, single superphosphate and triple superphosphate (F test P<0.05 for an isolated significance for level and source of P addition to the alkaline biosolid)

The interaction between levels and source of phosphorus added was significant ($F<0.01$) in relation to Ca^{2+} in this acidic soil (Figure 5 and Table 4). It was observed increases in the Ca^{2+} concentrations for all treatments. Nevertheless, the specific controls (T1, T5 and T9 on the Table 1) generated the larger increases indicating that the presence of higher quantities of pure alkaline biosolid in these treatments exert high influence upon the soil Ca^{2+} concentration. The level of 0.436% P from all sources of phosphorus addition, which have about 0.5 Mg at less alkaline biosolid in its composition, generated the better exchangeable concentrations of this nutrient compared to the other levels of P addition, increasing about 2.575 $cmol_c$ Ca^{2+} dm^{-3} from the partially acidulated rock phosphate Alvorada (Table 4). This fact must be due to the larger total Ca concentration present in the alkaline materials used in the sewage treatment process and, consequently, in its composition (Logan & Harrison, 1995). High negative correlations were verified between soil exchangeable calcium and levels of phosphorus addition from the individual sources (Figure 5). Plus, it was observed a decrease of the exchangeable soil Ca^{2+} concentration due to the increase in the levels of phosphorus addition and, consequently, a decrease in the pure quantities of alkaline biosolid in the treatments. A larger percentage of total calcium present on the P sources (CQFS-SC/RS, 2004; Novais & Smith, 1999) it must be too corroborated with these results, additionally. The small granulometry of the partially acidulated phosphate rock, more favorable to its dissociation upon the acidic conditions encountered initially in the soil, must have occasioned more dissolution as the sewage alkaline biosolid as the fertilizer with the consequent increase on the calcium concentration.

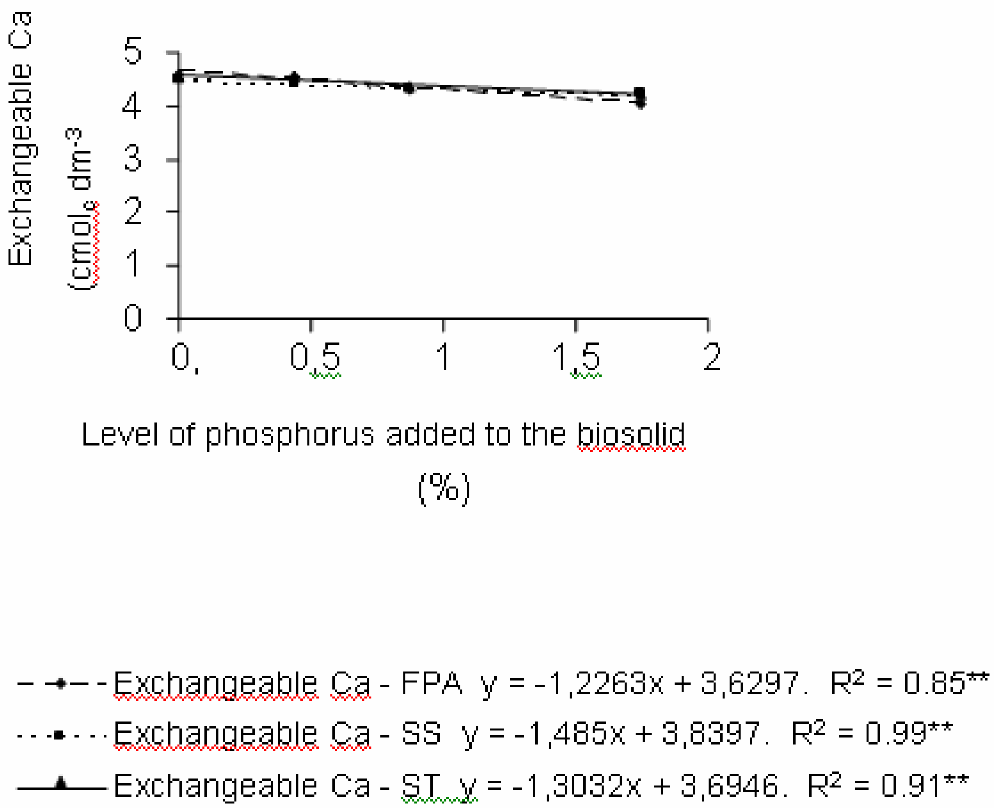

FIGURE 5 - Tendency curves of exchangeable calcium according the level of phosphorus added on an acidic Oxisol fertilized with alkaline biosolid added by four levels of phosphorus from the partially acidulated phosphate rock Alvorada (LPA-PAP), single superphosphate (LPA-SSP) and triple superphosphate (LPA-TSP) (F test $P<0.05$)

TABLE 4 - Means comparison of exchangeable calcium according the sources of phosphorus addition

SOP	LPA (%)			
	0	0.436	0.872	1.745
	-- Exchangeable Ca (cmol$_c$ dm^{-3})-------------------------------------			
PAP	3.475 b	3.575 a	2.150 b	1.575 ab
SS	3.950 a	3.075 b	2.500 a	1.300 b
TS	3.875 a	3.175 b	2.125 b	1.625 a
CV (%)	6.93			
DMS	0.318			

Note: Means followed by the same word at the vertical not differ estatistically by the Tukey test (P<0.05)
SOP: source of phosphrus added to alkaline sewage biosolid; LPA (%): level of phosphorus added to alkaline sewage biosolid; PAP: partially acidulated rock phosphate Alvorada; SSP: single superphosphate; TSP: triple superphosphate; CV (%): coefficient of variation, in percentage; DMS: least significant difference of the Tukey test.

The Figure 6 shows high positive correlations verified between soil Ca^{2+} and soil pH for individual sources of phosphorus added, confirming that, an increase in soil pH generates, concomitantly, an increase in soil Ca^{2+}. Several works have shown increases in soil Ca^{2+} due the application of alkaline biosolid to the soil (Barbosa et al., 2002; Guedes et al., 2006). Similar results were observed by Silva et al. (2001) that verified the Ca^{2+} content present in the alkaline biosolid and in the triple superphosphate led to increases of 4 to 8 times of the nutrient in the soil in comparison to the controls. Also according to Stehauer & Macneal (2004) Ca^{2+} increase concomitantly to the increase of alkaline biosolid and supplemental inorganic phosphatic fertilizer added to the treatments.

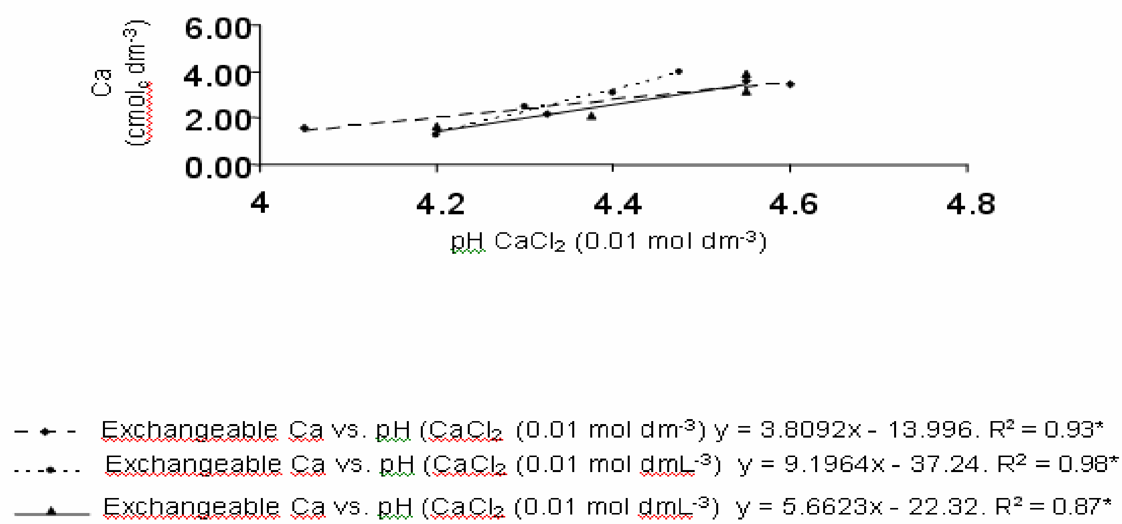

FIGURE 6 - Tendency curves of exchangeable calcium according the pH $CaCl_2$ on an acidic Oxisol treated with alkaline biosolid added by four levels of phosphorus from the partially acidulated rock phosphate Alvorada (PAP), single superphosphate (SSP) and triple superphosphate (TSP) (F test P<0.05)

The interaction between levels and sources of phosphorus addition to the alkaline biosolid was significant for Mg^{2+} in this acidic soil (F<0.01) (Figure 7 and Table 5). All the treatments increased this form of that nutrient in the soil. The best correlation was verified between soil exchangeable Mg^{2+} and the levels of phosphorus addition from the partially acidulated rock phosphate in comparison to the tendency curves generated for single superphosphate and triple superphosphate (Figure 7 and Table 5). However, the specific controls (0 % P) and the levels of 0.436% P and 0.872% P form the partially acidulated rock phosphate Alvorada and triple superphosphate showed similar results between each other and superior to the single superphosphate (Table 5). This fact, once more, it must be related with the elevated total concentration of Mg^{2+} present on the larger quantities of pure alkaline biosolid content in the mixtures related to this levels of phosphorus addition (Logan & Harrison, 1995). These same levels of phosphorus addition from the single superphosphate should present similar values of exchangeable magnesium to those obtained with partially acidulated phosphate rock and triple superphosphate. This results don't occurred, possibly, due to the errors in the analytic process or due the leaching of Mg^{2+} with the daily watering. Some works evaluated the concentration of soil Mg^{2+} according the incorporation of alkaline biosolids to the soil. From their was observed similar results in the Mg^{2+} concentration of soils which was decreased due to the leaching (Venâncio Gomes et al., 2005) and increases on the Mg^{2+} concentration due the increase of doses of alkaline biosolid (Simonete et al., 2003). 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+} on increases in the sum of bases and soil bases saturation.

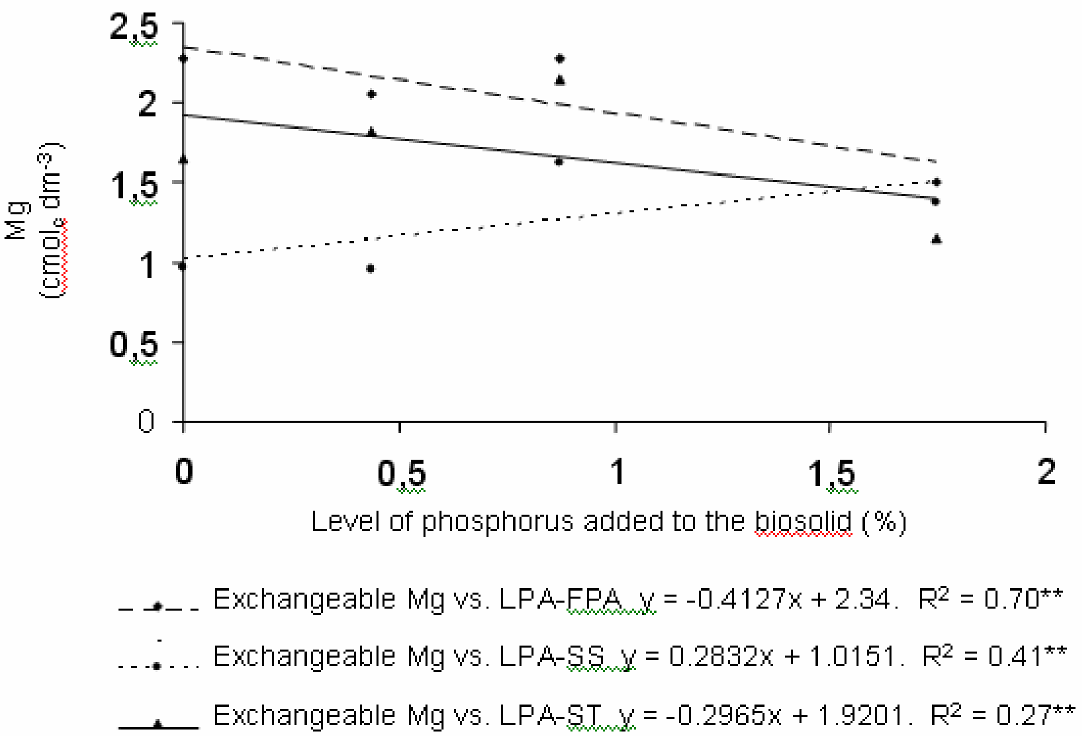

FIGURE 7 - Tendency curve of exchangeable magnesium according the level of phosphorus added to the alkaline biosolid from the partially acidulated phosphate rock Alvorada (LPA-PAP), single superphosphate (LPA-SSP) and triple superphosphate (LPA-TSP) (F test P<0.01)

CONCLUSIONS

Under the present experimental conditions the results of this study indicate that the treatments: i) increase the soil pH ($CaCl_2$ 0.01 mol dm^{-3}), exchangeable calcium and magnesium and decrease exchangeable aluminum and potential acidity of the Oxisol; ii) The assessed variables showed the larger alterations due to the levels 0.436% of P added to the sewage alkaline biosolid from the partially acidulated rock phosphate Alvorada and single superphosphate.

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TABLE 5 - Mean comparison of exchangeable magnesium according the sources of phosphorus addition

SOP	LPA (%)			
	0	0.436	0.872	1.745
	----------------------------------- Exchangeable Mg (cmol$_c$ dm^{-3})---------------------------			
PAP	2.275 a	2.050 a	2.275 a	1.500 a
SS	0.975 c	0.950 b	1.625 b	1.375 a
TS	1.650 b	1.825 a	2.150 a	1.150 a
CV (%)	15.44			
DMS	0.433			

Note: Means followed by the same word at the vertical not differ estatistically each other by the Tukey test (P<0.05).
SOP: source of phosphrus added to alkaline sewage biosolid; LPA (%): level of phosphorus added to alkaline sewage biosolid; PAP: partially acidulated rock phosphate Alvorada; SSP: single superphosphate; TSP: triple superphosphate; CV (%) = coefficient of variation, in percentage; DMS: least significant difference of the Tukey test

REFERENCES

1. BARBOSA, G.M.C.; TAVARES FILHO, J.; FONSECA, I.C.B. Avaliações de propriedades físicas de um eutroférrico tratado com lodo de esgoto por dois anos consecutivos. **Sanare**, v. 17, n. 17, p. 94-101, 2002.
2. BELTRÁN, R.R., SILVEIRA, R. I.; PASSOS, M.J. Disponibilidade de fósforo para plantas de arroz avaliada por extratores químicos. **Scientia Agricola**, v. 55, n. 2, p. 233-241, 1998.
3. CHRISTIE, P.; EASSON, D.L.; PICTON, J.R. e LOVE, S.C.P. Agronomic value of alkaline-stabilized sewage biosolids for spring barley. **Agronomy Journal**, v. 93, n. 1, p. 144-151, 2001.
4. CQFS - SC/RS - COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO - RS/SC. **Manual de adubação e de calagem para os Estados do Rio Grande do Sul e de Santa Catarin**a. 10 ed. Porto Alegre: Sociedade Brasileira de Ciência do Solo, 2004. 400 p.
5. FIA, R.; MATOS, A.T.; AGUIRRE, C.I. Características químicas de solo adubado com doses crescentes de lodo de esgoto caleado. **Engenharia na Agricultura**, v. 13, n. 4, 287-299, 2005.
6. GUEDES, M.C.; ANDRADE, C.A.; POGGIANI, F.; MATTIAZZO, M.E. Propriedades químicas do solo e nutrição do eucalipto em função da aplicação de lodo de esgoto. **Revista Brasileira de Ciência do Solo**, v. 30, n. 2, p.267-280, 2006.
7. KORNDÖRFER, G.H.; LARA-CABEZAS, W.A.; HOROWITZ, N. Eficiência agronômica de fosfatos naturais reativos na cultura do milho. **Scientia Agricola**, v. 56, n. 2, p. 391-396, 1999.
8. LOGAN, T.J.; HARRISON, B.J. Physical characteristics of alkaline stabilized sewage sludge (N-Viro Soil) and their effects on soil physical properties. **Journal of Environmental Quality**, v. 24, n. 1, p. 153-164, 1995.
9. MELO, W.J.; MARQUES, M.O. Potencial do lodo de esgoto como fonte de nutrientes para as plantas. In: BETTIOL, W. e CAMARGO, O.A. (Eds.). **Impacto ambiental do uso agrícola do lodo de esgoto**. Jaguariúna: EMBRAPA Meio Ambiente, 2000. p. 109-141.
10. NOVAIS, R.F.; SMITH, T.J. **Fósforo em solo e planta em condições tropicais**. 1. ed. Viçosa: Editora da Universidade Federal de Viçosa, 1999. 399 p.
11. OLIVEIRA, F.C.; MATTIAZZO, M.E.; MARCIANO, C.R., ROSSETO, R. Efeitos de aplicações sucessivas de lodo de esgoto em um Latossolo Amarelo Distrófico cultivado com cana-de-açucar: Carbono orgânico, condutividade elétrica, pH e CTC. **Revista Brasileira de Ciência do Solo**, v. 26, p. 505-519, 2002.
12. OSZTOICS, C.; NÉMETH, B.; MAGYAR, M. Influence of phosphate fertilizer sources and soil properties on trace element concentrations of red clover. **Communications in Soil Science and Plant Analysis**, v. 36, n. 4-6, p. 557-557, 2005.
13. SILVA, F.C., BOARETTO, A.E., BERTON, R.S. Efeito de lodo de esgoto na fertilidade de um argissolo vermelho-amarelo cultivado com cana de açúcar. **Pesquisa Agropecuária Brasileira**, v. 36, n. 5, p. 831-840, 2001.
14. SILVA, F.C.; BOARETTO, A.E.; BERTON, R.S.; ZOTELLI, H.B.; PEIXE, C.A.; MENDONÇA, E. Cana-de-açúcar cultivada em solo adubado com lodo de esgoto: nutrientes, metais pesados e produtividade. **Pesquisa Agropecuária Brasileira**, v. 33, n. 1, p. 1-8, 1998.
15. SILVA, F.C.; BOARETTO, A.E.; BERTON, R.S. Características agrotecnológicas, teores de nutrientes e de metais pesados em cana-de-açúcar (soqueira), cultivada em solo adubado com o lodo de esgoto. In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 25., Viçosa. **Anais**...Viçosa: SBCS/UFV, 1995. p. 2279-2287.
16. SIMONETE, M.A.; KIEHL, J.C.; ANDRADE, C.A.; ALMEIDA TEIXEIRA, C.F. Efeito do lodo de esgoto em um Argissolo e no crescimento e nutrição de milho; **Pesquisa Agropecuária Brasileira**, v. 38, n. 10, p. 1187-1195, 2003.
17. SLOAN, J.J.; BASTA, N.T. Remediation of acid soils by using alkaline biosolids. **Journal of Environmental Quality**, v. 24, n. 6, p. 1097-1103, 1995.

18. STEHOUWER, R.C., E MACNEAL, K.E. Effect of alkaline-stabilized biosolids on alfalfa molybdenum and copper content. **Journal of Environmental Quality**, v. 33, n. 1, p. 133-140, 2004.
19. VENÂNCIO GOMES; S.B.; NASCIMENTO, C.W.A; BIONDI, C.M.; ACCIOLY, A.M.A. Alterações químicas em argissolo tratado com lodo de esgoto, **Caatinga**, v. 18, n. 3, p. 185-194, 2005.
20. VIEIRA, R.F.; TANAKA, R.T.; TSAI, S.M.; PÉREZ, D.V.; SOUSA SILVA, C. M. M. Disponibilidade de nutrientes no solo, qualidade de grãos e produtividade da soja em solo adubado com lodo de esgoto. **Pesquisa Agropecuária Brasileira**, v.40, n.9, p. 919-926, 2005.

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