Land Reclamation Recovery with the Sewage Sludge Use

Cristina Rincon Tamanini[1*]**; Antônio Carlos Vargas Motta**[1]**; Cleverson Vitório Andreoli**[2]
and Benno Henrique Doetzer[3]

[1] *Universidade Federal do Paraná; Curitiba - PR - Brasil.* [2]*Departamento de Solos e Engenharia Agrícola*; *Rua dos Funcionários, 1540; mottaacv@ufpr.br; 80035-050; Curitiba - PR - Brasil.* [3]*Companhia de Saneamento do Paraná; Rua Eng^{os} Rebouças, 1376, 80215-900; Curitiba - PR - Brasil.* [4]*EMATER; Rua da Bandeira, 500; Curitiba - PR - Brasil*

ABSTRACT

In this work, investigations were carried out with five treatments [control, three doses of lime stabilized sludge (60, 120, 240 Mg ha^{-1} in dry base) and soil corrective plus mineral fertilizer] to evaluate the immediate recuperation of a borrowed area. The application of stabilized alkaline sewage sludge acted as an acidity corrective, allowed the increase in the organic matter contents (21 to 43.5g dm^{-3}) and available P (44 to 156 mg dm^{-3}). Even with the use of the highest dose, no increase in the concentration of 32 analyzed metals was observed, due to the low concentration of metals in the sludge. The experiment showed that short term restoration of degraded area was possible by using high rates of sewage sludge without metal contamination.

Key words: sewage sludge, land reclamation, soil fertility, soil chemistry, degraded area

INTRODUTION

One of the biggest challenges of the humankind is to conciliate the present development model with the reduction of environment impact and to promote the mitigation of the existing problems. Despite that the impacts originate from the antropic action, the natural resources utilization is necessary, thus the human occupation, the industrial activities and the agricultural systems must be compatible with the ecosystem (FAO 1999; Lima, et al., 2002; Ceccon et al. 2006).
Currently, a very serious problem observed in the cities with a wastewater treatment plant, is related to the destination of the sludge produced in the sewage treatment plants. The suitable final destination of the sludge is fundamental to the

treatment facilities to avoid the problems, which come from inadequate alternatives of the final disposal (Sperling and Andreoli, 2001). Many researchers have suggested that the agricultural use of sludge is a reliable way to dispose it (Tsutiya, 2001; Andreoli et al., 2001). The agricultural utilization promotes the use of this residue that is rich in organic matter and nutrients, and can be recycled and returned to the soil as a fertilizer.
The sewage sludge can also be used in the degraded sites with a series of advantages to the establishment and maintenance of the vegetation as the soils from these sites lack in organic matter, nutrients and the biological activity which all can be provided by the sewage sludge. The use of sewage sludge in mitigation and re-vegetation of the degraded soils has been shown to be safe to the

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* Author for correspondence

humans and to the environment (Tsutiya, 2001; Sopper, 1993; Andreoli et al., 2001). However, the mixture of sewage sludge with other kinds of residues may add toxic elements, undertaking the quality of the material and limiting its agricultural land application (Andreoli et al., 2001).

The objective of this study was to evaluate the potential of high rates application of sewage sludge in the recuperation of degraded site, using the forage crop yield and soil chemical properties as the indicator and compare the sewage sludge with the mineral fertilizer.

MATERIALS AND METHODS

The experiment was performed in an area of approximately 5 ha used as borrowed area of soil material for the expansion of the International Airport in São José dos Pinhais. The loss of soil surface occurred around 1990, with the complete withdrawal of the topsoil classified as the anthropogenic soil (at the beginning an Alisoil, EMBRAPA, 1999) and geologically originated in Guabirotuba Formation (EMBRAPA, 1984). After 10 years of the soil surface loss, the area did not receive mitigation intervention and was almost bare due to the poor soil condition.

The area was located between the coordinates 22J0684582 and UTM 7174198 and 22J0684636 and UTM 7174195, at an altitude of 908m. The landscape had a slight undulated to undulated topography of half slope with low possibility of natural regeneration. The region's climate is classified as Cfb (KÖPPEN), subtropical without dry season and annual precipitation between 1,450 and 1,660 mm. In the corresponding period to the development of the activities (January to April of 2003), the average temperature was 20.9ºC and total precipitation of 481mm (SIMEPAR, 2004).

The experiment comprised five treatments, consisting of control (only with liming), three rates of sewage sludge (57.3, 114.5 and 229.1Mg ha^{-1} in dry matter) and one additional treatment where lime and mineral fertilization was applied in order to supply the necessity of the sowing crop.

The experimental area of approximately 2000m^2 received an equivalent of 2.6Mg ha^{-1} of dolomitic lime filler (percent of effective calcium carbonate of 88%) over the whole area to homogenize, facilitate the sowing and stimulate the vegetation growth. Then, it was submitted to sub soiling and harrowing. After the soil descompaction, the plots, measuring 10x8m, were established, keeping one-meter distance to avoid the contamination during the sewage application.

Around 30 days before the sowing, the plot related to the mineral fertilization, was amended with extra lime application, (15Mg ha^{-1}) in order to achieve 70% of base saturation. During the sowing, this treatment received 20kg ha^{-1} N, 110kg ha^{-1} P$_2$O$_5$, and 80 and 110K$_2$O ha^{-1} as urea (45%N), super phosphate (18%P$_2$O$_5$) and potassium chloride (60%K$_2$O), respectively. Sidedress application of 180kg ha^{-1} N was applied as urea, according to the recommendations of the Fertilization Committee of Soil from the States of Rio Grande do Sul and Santa Catarina (1989).

The sewage sludge was produced at the Belém sewage treatment plant, located at Curitiba city belonging to SANEPAR Company. The stabilized sewage sludge was produced through the long-term aeration process and was made hygienic by adding 10 to 20% of its dry weight with CaO and kept for a period of 70 days. The estimated sewage sludge rates were 0, 60, 120 and 240Mg ha^{-1} (dry base) and corrected according to the humidity concentration (15.3%) and global density average of 0.96g cm^{-3}.

The sewage sludge was applied to the soil surface with a specific equipment piece for sewage, followed immediately by the incorporation by sowing. After 31 days, pearl millet (*Pennisetum americanum*) was sowed in the whole experimental area by homogeneously spreading the seeds and slight incorporation by the disc.

Table 1 - Fertilization parameters of sludge applied to degraded site.

Lime stabilized sludge	N total	P*[4] extractable	P (total)	K extractable	OM	pH CaCl$_2$	C/N*[1]	C*[2,4]	CEC*[3,2]	U
			g kg^{-1}				%	g dm^{-3}	cmol$_c$ dm^{-3}	%
10-20%	6.1	5.0 (P$_2$O$_5$)	7.6 (P$_2$O$_5$)	0.67 (K$_2$O)	100.7	8.1	9.2	60.6	31.9	85.9

Note: *[1]C/N: carbon nitrogen relation, *[2]analysis according to defined methodology to soil analysis, *[4]neutron citrate of ammonium extraction, *[5] organic carbon.

Table 2 - Chemical elements found on sewage sludge applied to the area.

Ag	Ba	La	Li	Sr	Al	Ca	Fe	K	Mg	Mn	Na	P	Ti
		mg kg^{-1}						g kg^{-1}					
31	415	114	5.1	76	28	59	20	2.0	37	0.6	0.4	11.0	0.2

The sewage sludge was analyzed for pH, total N, organic matter, humidity, C:N, soluble P and exchangeable K through the methodology of Lanarv (1982), Na$^+$ according to the methodology defined by EMBRAPA (1997), colorimetric organic carbon as described by Raij and Quaggio, (1983) (Table 1). The total concentration of Cd, Cu, Ni, Zn, Cr, Pb, Hg, Ag, Ba, La, Li, Sr, Al, Ca, Fe, Mg, Mn, Na, P, and Ti was determined through multi acid digestion (chloridric, fluoridric and nitric acids, and perchloric drops) and measured by ICP-OES (Optical Emission Spectrometer Inductively Coupled Plasma Spectrometers) adapted by Fernandes et al. (1999) (Table 2; Fig. 1). The soil sample for the chemical analysis was collected from each plot, before the treatment application and after the pearl millet harvesting. One sample for each plot was collected from 20 points at a depth of 0-0.2m. For the chemical and mineralogical characterization a sample was made composed by all the other collected samples, mixed before the sewage sludge application and one sample composed by each experimental unit after the pearl millet harvest.

The soil samples were analyzed for pH CaCl 0.01M, base saturation, exchangeable Al^{+3}, potential acidity to pH 7.0 (H$^+$ + Al^{+3}), Ca^{+2}, Mg^{+2}, K$^+$, CEC, and P (soluble) according to EMBRAPA (1997), PAVAN et al. (1992) to K and P (Mehlich – I), and organic C for colorimetric as described as Raij and Quaggio (1983). For K analysis, the extraction methodology through ammonium acetate described by Knudsen et al. (1982) was used. Total contents for Ba, Co, Cr, Fe, La, Li, Mn, Ni, Sr, Ti, Zr, V, Y, Pb, B, Cu, Ni, Zn, Cr, and Hg were determined by multi acid digestion (hydrochloric, fluoric and nitric acids, and percloric drops) and plasma determination ICP – OES (Table 3).

Table 3 - Total content and heavy metals and average content related to degraded site fertility.

pH CaCl$_2$	Al^{+3}	H$^+$+Al^{+3}	Ca^{+2}	Mg^{+2}	K$^+$	CEC^1	P	C	V*^{2}	clay
			cmol$_c$ dm^{-3}				mg dm^{-3}	g dm^{-3}	%	g kg^{-1}
4.10	12.4	20.4	1.12	0.84	0.13	22.47	0.30	14.5	8.9	490
Al	**Ca**	**Fe**	**K**	**Mg**	**Mn**	**P**	**Ti**	**Ba**	**Co**	**Cr**
			g kg^{-1}					mg kg^{-1}		
60.2	0.5	45.0	3.1	3.8	0.3	0.2	1.1	105.4	10.5	84.2
Cu	**La**	**Ni**	**Li**	**Pb**	**Sr**	**V**	**Y**	**Zn**	**Zr**	
				mg kg^{-1}						
31.2	24.0	26.0	16.5	80.8	20.4	59.3	4.4	61.8	19.7	

Note: ^{*1} CEC- cation exchangeable capacity for pH 7,0, ^{*2} V%: bases saturation related to CEC pH 7,0.

The delineation was used in randomized blocks, with parcels of 8x10m, with one meter of distance. The statistical evaluation was made through the analysis of regression and variance (*Fisher*) and average comparison (*Tukey*, probability of 5%).

RESULTS AND DISCUSSION

Sewage Sludge
The contents of Hg, Cd, Cr, Cu, Ni, Pb, and Zn were used as the indicators of contamination. The results from the sewage sludge shown in Fig. 1 were compared to the maximum acceptable limits established by state laws (IN–IAP - Proposed Normative Instruction of the Ambient Institute of Paraná, 2000,) and the sewage sludge class B from EPA (Environmental Protection Agency, 1997, CFR part. 503). The comparative results indicate that the concentration values observed on sewage sludge represent 2; < 15; 6.3; 13.4; 9.3; 8.9; 21.7% to Hg, Cd, Cr, Cu, Ni, Pb, and Zn respectively, of the limit established by IN–IAP. With the exception of Zn, the heavy metals level

represented less than 15% of the maximum established limit. In relation to EPA, the respective concentrations were 0.6; 3.5; 2.1; 3.1; 6.7; 8.0 and 7.2%, indicating that the origin of the used material is predominantly domestic with low contamination. Corroborating with our finding, PEGORINI (2002), MIYAZAWA et al. (1996), BARRIQUELO et al. (2003) and WISNIEWSKI et al. (1996) have also found values well below the

maximum limit for heavy metal for sewage sludge with predominantly domestic origin.

The amount of heavy metals added by the high doses of sewage sludge did not offer risk of contamination to the soil in the reclamation process studied. The Cd concentration in the sludge was below the detection limit of 3mg kg^{-1} (non-presented data) of the chemical analysis, indicating that the concentration has been below the established limit.
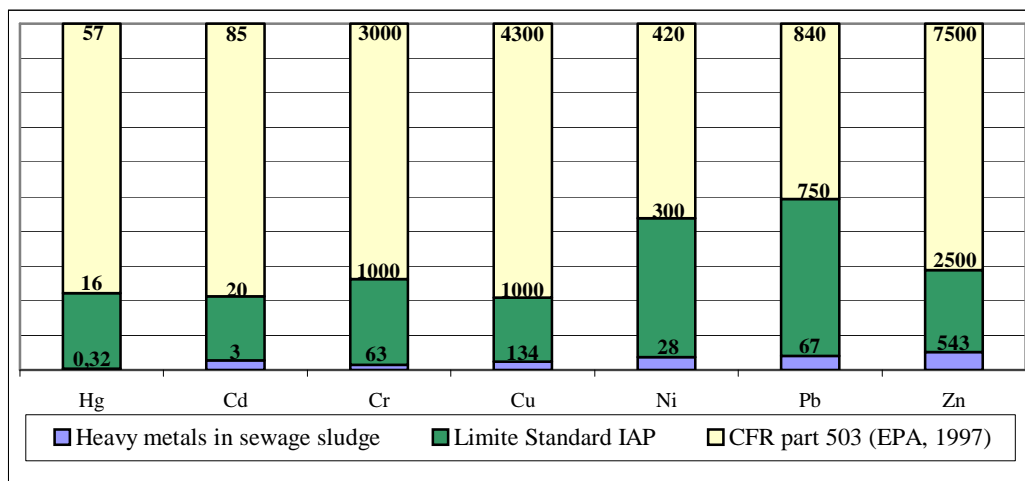
Figure 1 - Concentration of heavy metals (mg kg^{-1}) present in the sewage sludge in comparison with the suggested by in-iap and cfr part 503 (epa, 1997).

Soil

Carbon and organic matter

The results indicated that there was a proportional increase between the sewage sludge rates and C concentrations in the soil (Fig. 2). The treatment which received the highest sewage sludge rate (240Mg ha^{-1}) presented a C concentration 2 times bigger than the treatment with mineral fertilization, which had the lowest concentrations as it received only addition of culture residue to this treatment. It was observed, therefore, that the application of organic residues favoured the accumulation of this element in the soil as observed by Nascimento et al. (2004), Barbosa (2000), Berton et al. (1989) and Siengenthaler and Stauffer (1991); the last one working with sewage sludge and dairy manure.

These results have high relevance because the organic matter is one of the most important soil

quality indicator (Doran, 1996), and one of the main indicators of the degraded soils mitigation. The results showed that the use of high rates of sewage sludge allowed a fast soil recovering as the C value obtained after the application was close to the value found in the non-degraded areas in the origin. Almeida (2003) observed a high improvement in the biological activity at the same site after sewage sludge application.

These results confirmed the difficulty of a fast increase of C through the mineral fertilization and liming as demonstrated by Favaretto (1996), who observed a slow increment of C, limited to the first soil centimeters, indicating that the organic matter recuperation was a slow continuous process and dependent on the tillage system.
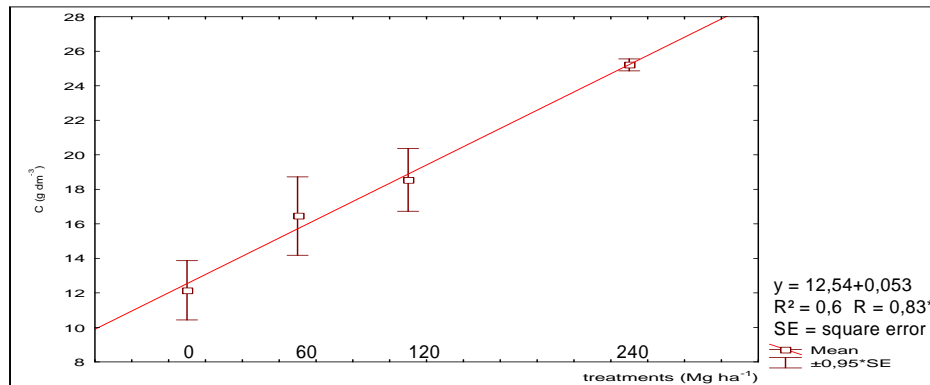
Figure 2 - Level of C in the soil after high rates of sewage sludge application.

The sewage sludge application promoted a fast mineralization of the organic matter, transforming it into stable composts in the soil maintaining itself for many years Sanches (1981). The high clay content and activity (high specific surface) and the low concentration of the organic matter at the beginning of the experiment probably were soil properties which should contribute to maintaining a large increment of C in the soil. Castro et al. (2002) observed higher concentrations of C in locals without soil wastage and fertilization with the use of sewage sludge, where there is a higher amount of organic matter.

Phosphorus

A linear increase in the availability of P was obtained according to the dose applied as sewage sludge (Mehlich I), changing from fractions of 1 mg P kg^{-1} soil to more 26 mg P dm^{-3} with the usage of 60Mg ha^{-1} of sewage sludge (Fig. 3b). This meant that the P availability passed from a deficient level to very high values with lower sewage sludge rate according to SOIL FERTILITY COMMITTEE of the STATES of RS and SC; (1989). Build up P availability has been shown in different conditions by Nascimento et al. (2004), Berton et al. (1989), Silva et al. (1998) and Wisniewski et al. (1996), even with a rate application lower to the P added in this study. The high rates of sewage sludge applied will probably have as a result a residual effect for many decades, since McCollum (1991) showed P elevation (in sandy soils with a low buffer capacity) to values between 100 and 120mg dm^{-3}, allowed the corn production maintenance for 14 years without the addition of P through fertilizer.

The application of sewage sludge in order to increase the P in the soil to such high values must be done carefully in the areas susceptible to runoff, because it might arouse water streams contamination, as has been observed in the areas which received large amounts of animal residues for a long period of time (Daniel et al., 1998).

The application equivalent to 1,260mg kg^{-1} generated an increase of approximately 156mg dm^{-3} (240Mg ha^{-1} of sewage sludge), which meant an increase of approximately 12% at the available form, indicating a high fixation capacity of this element in the soil. The high amount of 2:1 with hydroxide Al interlayer in this soil might have large P potential for specific absorption like as observed for McLauhghlin et al. (1981). Thus, the addition of 1mg kg^{-1} of P through sewage sludge, elevated the available P in the soil to 0.06 units.

There was a high P build up, from 200mg P kg^{-1} to more than 1,100mg kg^{-1} (Fig. 3a) and like Mehlich P extracted, a linear increment was observed for total P as result of sewage sludge rates increment. These increases were very expressive since the initial content of near 200mg kg^{-1} was compared to the value observed at the Cerrado region, highly weathered soils, known as very poor in P (Goedert et al., 1986) passing to values higher than 1,000mg kg^{-1}, which was the content of the rich soils of the cultivated areas from Campos Gerais region (Sá, 1994). Increase in total P contents have also been observed through the long usage of animal residues as it has a permanence of P in the soil, due to a low mobility (Sharpley et al., 1994). The use of sewage sludge allowed an immediate correction of the P deficiency, concentrating the stocks in the soil which permit the supply to the plants for a long period of time
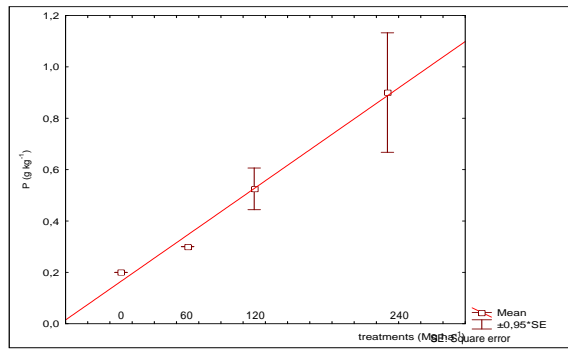
Figure 3 a - $y = 0.003x + 0.16$ $R = 0.76*$ $R^2 = 0.58$.
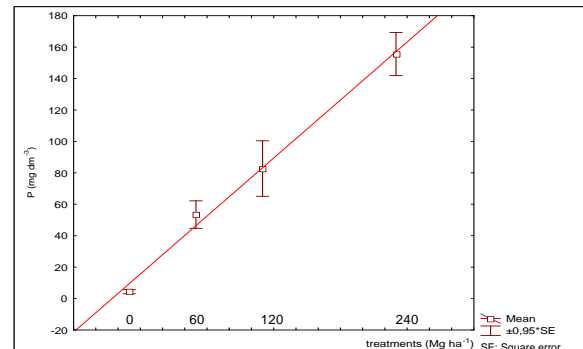
Figure 3b - $y = 9.44 + 0.61x$ $R = 0.92*$ $R^2 = 0.86$.

Figure 3a, b - P Levels in the soil after high doses application of sewage sludge.

Potassium

The difference between the values extracted by the two methods was evident (Fig. 4b,c), due to the high activity clays participation in charge generation. The extraction method with ammonium acetate showed higher extraction capacity compared with Mehlich I. This has been associated with the presence of NH_4^+, which has approximately the same ionic radium as the K^+, being able to substitute it at the sites of high energy (Nemeth, 1982).

Different from P, the K availability was not affected or decreased at the extracted concentrations through Mehlich I methods and ammonium acetate, respectively. This result was not expected, due to the quantity of K applied through the sewage sludge which was quite above the usual utilized in the chemical fertilizations. However, no change in the K^+ concentration through the use of sewage sludge has been observed in many conditions (Silva et al., 1998; Wisniewski et al., 1996) utilizing Mehlich I as an extractor.

A reduction in ammonium acetate extracted K^+ could be related to the soil mineral and chemical characteristics, clay presence 2:1 (smectite in most parts, vermiculite and mica) and high concentration of Al^{+3} (Table 1 and Fig. 7). Probably part of this Al^{+3} might have come from the partial chlorotization of the high activity clays and could be blocking the internal charge sites of the clays 2:1. The pH elevation, through the application of sewage sludge, could have caused an Al^{+3} decrease, with an increase in the capacity of the K fixation in the soil, causing a reduction in the K^+ extraction capacity. Nemeth (1982) working with the Brazilian soil, showed that lime application increased the K^+ fixation in some soils due to the decrease in Al and Fe which were blocking the selective sites. The increase of the CEC to pH 7.0 (non-presented data) when sewage sludge was applied gave proof for this hypothesis. However, it was not possible to confirm this fact since CEC increment might also been related to the organic C enhancement shown before.

Besides the time of collection of clay mineral, the soil samples might, in part, have also affected the results, once these samples were taken at the millet development period and approximate values near 100kg of K (non-presented data) were found at the upground parts. Wastage due to leaching might have had little influence due to the high CEC in the soil and high fixation capacity. Anjos (1999) observed loss because of leaching between 10 and 16% of the K applied, in the soil with 6.6cmol$_c$ dm^{-3} of CEC after two years.

The total K content in the soil was reduced at the treatments which received sewage sludge (Fig. 4a). A probable explanation could be the addition of basic components which could be decreasing the acid attack of the total extraction.

Thus, the use of the lime stabilized sewage sludge effects on K were adverse and could not be taken to other soil conditions of Brazil, because of high activity of clay in high acidity conditions.
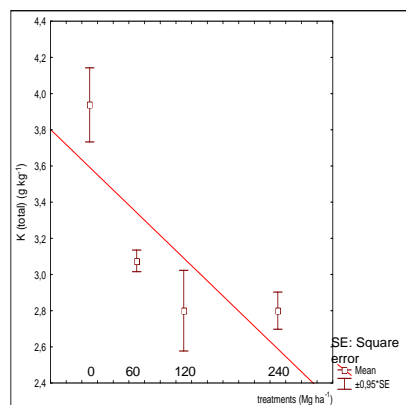
Figure. 4a - y = -0.004x+3.58   R=0.67* R^2=0.45.
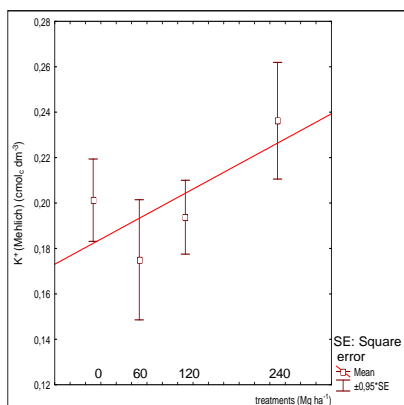
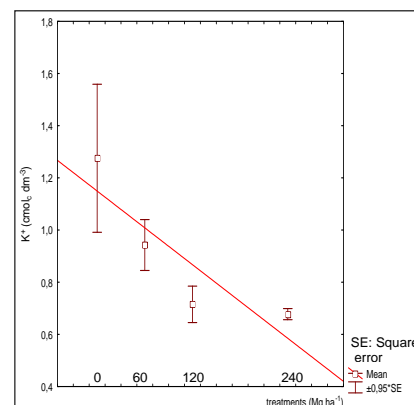**Figure 4b -** y=0.182+0.0002x   R=0.35[ns] R^2=0.13.

Figure 4c - y= -0.002x + 1.15   R=0.56* R^2=0.32.

Figure 4a,b,c - K levels, K^+ (mehlich) and K^+ (ammonium acetate) in the soil after high doses of sewage sludge application.

Calcium

A linear increase between total Ca and sewage sludge rate was found. The treatment with the highest rate of sewage sludge (240Mg ha^{-1}) provided more Ca than the other treatments, practically four times the quantity on the treatment with 60Mg ha^{-1} and being around 8.3 fold superior when compared with the control treatment (Fig. 5a).
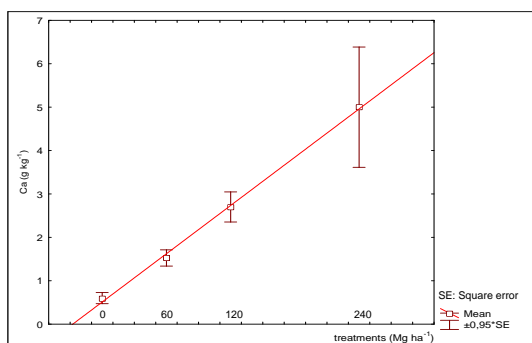
An elevation at the exchangeable Ca concentrations was observed according to applied rate, having the tendency of stabilization at the higher doses with the values around 13cmol$_c$ dm^{-3} (Fig. 5b). The results Berton et al. (1989), were similar to those of Silva et al. (1998), Nascimento et al. (2004), Barbosa (2000) and Anjos (1999) who found a Ca increment when sewage sludge was applied.
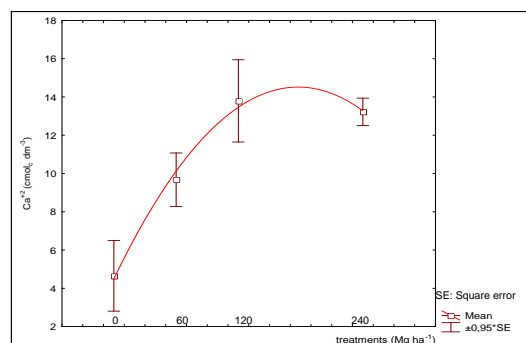

Figure 5a -   y = 0.019x + 0.5   R = 0.78* R^2 = 0.61.

Figure 5b -   y = - 0.0003x^2 + 0.113 x + 4.48   R = 0.77* R^2 = 0.60.

Figure 5a, b - Total and changeable Ca levels in the soil after high doses of sewage sludge application.

The exchangeable concentrations of Ca were classified as high in all the treatments due to Ca addition, not only through the sewage sludge, but also through the lime in all the treatments. The total Ca and exchangeable contents in the soil at the treatment which received the lowest doses of sewage sludge (60Mg ha^{-1}) was almost twice as bigger as the treatment which received the lime, showing the highest efficiency of the material

application at the availability of Ca^{+2} in the soil related to lime utilization.

The high Ca availability in the treatments which received the sewage sludge compared to the one with the lime application could be explained by a faster liberation of calcium hydroxide compared to CaCO$_3$ from the lime. Though, the utilized lime could have concentrations of Ca lower than what was expected, for this reason there was no

expected increase of total Ca and the reduction of Al^{+3} on the treatment.

Magnesium

For the total Mg, no statistical variation among the treatments was observed, despite the tendency of elevation of its concentrations. The Mg

contribution to the treatment with the mineral fertilization showed a higher concentration when compared to the control, probably because of a high quantity of this element was added to the soil through the liming. However, all the treatments obtained high concentrations of this element (Fig. 6).
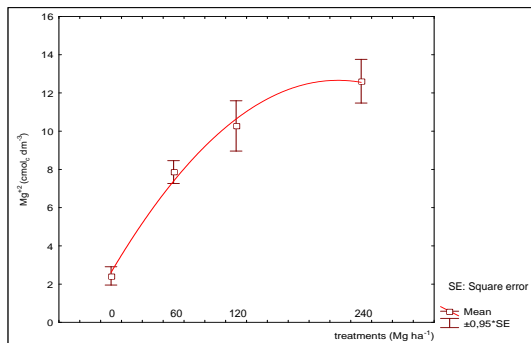

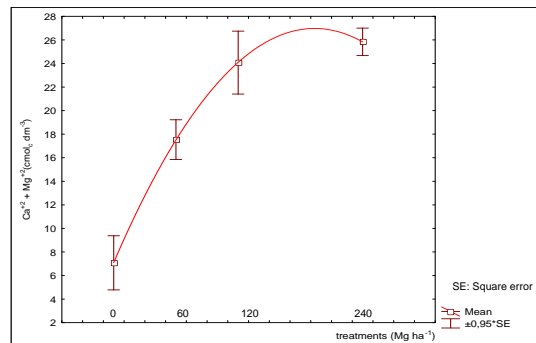**Figure 6a -** y = - 0.0002x^2 + 0.092x + 2.61   R=0.91* R^2=0.82.

Figure 6b - y = - 0.0005x^2 + 0.205x + 7.093   R=0.89* R^2 = 0.80.

Figure 6a, b - Exchangeable Mg^{+2} and Ca^{+2} + Mg^{+2} concentrations in the soil after application of high doses of sewage sludge.

In disagreement with Mg^{+2} concentrations, the study made by Anjos (1999) did not show statistical differences in relation to the treatments with the successive applications of the sewage sludge, attributing to the fact that despite the addition of 1,173kg ha^{-1} of Mg^{+2}, this concentration was not enough to elevate the concentration of the element. This data contradicted the ones obtained in the studied soil, where high concentration of Mg and the soil saturation were quickly reached at the doses of 120 and 240Mg ha^{-1}.

Like exchangeable Ca^{++} and Mg^{++}, the combined value (Ca^{++} + Mg^{++}) showed progressive decrease of exchange value with the sewage sludge rate due to the reduction of the reactions in the soil as a result of the pH elevation (Fig. 6a,b). The control treatment presented Ca^{+2}+Mg^{+2} concentrations in the soil, 3.6 times lower than the treatment which received the highest dose of sewage sludge (240Mg ha^{-1}). The soil buffer capacity at pH around 5 to 6 has also influence on Mg with a tendency to the stabilization of this element in the soil with higher doses.

Favaretto (1996) also observed better results on Ca and Mg concentrations in the treatments which received the sewage sludge in relation to the other treatments, compensating the loss due to upground

part export, according to the low uptake of these nutrients by the plants.

A decrease was observed in the Ca:Mg ratio with the values near 3, almost up to 1 in the treatments which received the sewage sludge. This close ratio could generate nutritional imbalance in the cultivated plants since there was no adequate relation between these two elements. At relations near 1, Ca absorption decrease might occur which impaired the vegetation growth. The highest Mg absorption in relation to Ca was observed at the pearl millet in the treatments which received sewage sludge (data not presented), though without impairing the vegetation growth.

pH in CaCl$_2$ 0.01m and aluminum

A linear increment of the soil pH in relation to the applied rates was observed, reaching values near 5.4 for 120Mg ha^{-1} of sewage sludge (Fig. 7a), value usually adopted to the main crops of the region. Thence, higher doses than 120 Mg ha^{-1} could compromise the future productivity, leading to nutritional imbalance (Andreoli et al., 2001) and micronutrients deficiency as observed by Rodrigues et al. (1999). At 240Mg ha^{-1} of sewage sludge, the pH reached maximum value near the restriction band for the crops development (data not shown). The rate of 120Mg ha^{-1} could not be used as reference to the other tropical soils as the

soil utilized presented high buffer capacity as proved by the value of 20.4cmol$_c$ dm^{-3} of H$^+$+Al^{+3}, which in general represented the double value observed in the tropical soils.

The exchangeable Al^{+3} showed exponential reductions due to the sewage sludge rate application (Fig. 7b). The Al^{+3} behaviour was expected as the soil pH was originally very low and increased with the sewage sludge application. The Al^{+3} concentration reduction might have resulted yet from the Al^{+3} complexation, due to the organic matter (Ernani and Gianello, 1993) and sewage sludge (Liu and Hue, 1996; Hue, 1992).
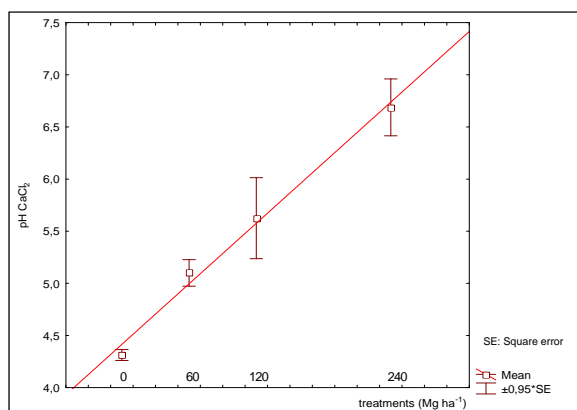
When Al^{+3} is held tightly by the organic matter, the KCl 1N extraction solution can only displace it partially (Hargrove and Thomas, 1981; Ahmad and Tan, 1986). However, others extraction solutions were able to extract more Al^{+3}, especially from the soil organic matter and in the soil with pH about 4.8, which was higher limit for Al^{+3} extraction by KCl 1.0N (Hargrove and Thomas, 1981; García-Rodeja et al., 2004). Thence, organic matter influenced Al^{+3} reactions in a wide range of soil pH.

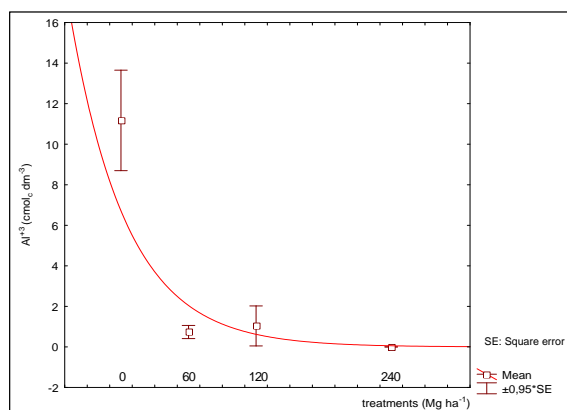**Figure 7a -** pH = 0.0097x + 4.41 R= 0.88* R^2 = 0.77.

Figure 7b - Al^{+3} = 5.5$^{-0.0198x}$ R=0.82* R^2 = 0.68.

Figure 7a, b - pH levels CaCl$_2$ 0.01m and Al^{+3} in the soil after high application doses of sewage sludge and per millet.

At the treatment which received 120Mg ha^{-1} of sewage sludge, an Al^{+3} concentration of around 1.0cmol$_c$ dm^{-3} was observed at a 5.6 pH, which was not expected, as theoretically there should not be Al present in this form at a pH higher than 4.8. This fact could be explained through a unique repetition of this treatment, which presented this element at the soil profile, elevating this way the treatment average.

Due to high activity of the clay and high Al^{+3} concentrations, the liming was not enough to neutralize the Al^{+3} in the treatment which received mineral fertilization. It would also be important to emphasize that the lime quantities added by the sewage sludge to the soil were high enough to achieve neutral pH. However, this soil pH was not reached, because the soil had a high buffer capacity. The lime stabilized sewage sludge showed to be a very efficient at the activity correction, being able to decrease the land reclamation costs with the use of correctives.

Parameters Related To Heavy Metals

The usage of high rates of the sewage sludge affected the total concentration of 18 elements (Ba, Co, Cr, Fe, La, Li, Mn, Ni, Sr, Ti, V, Hg, Cu, B, Zn, Zr, Pb and Y) in the soil but significant differences were observed for only Zn, Ti and B. Some elements such as B, Fe and Zr showed a tendency to decrease in the soil after the application of sewage sludge (Table 4), while others presented increase (Hg, La, Cu, and Pb). Pegorini (2002), Nascimento et al. (2004), Miyazama et al. (1996) also did not observe any significant increase in the heavy metals concentration after sewage sludge application or urban garbage compost in the soil. Even for the elements with significant differences, the concentrations in the soil were maintained at safe levels according to IN-IAP, Company of Environmental Sanitation Technology (2001) and Environment Protection Agency (1983).

The application of high doses of the sewage sludge without industrial contaminants to the scoured site indicated no inconvenience in relation to an increase in the levels of heavy metals in the soil (Table 4), with no risk of contamination. It is possible that the high quantity of organic matter at this kind of residue, strongly retained the fractions of these metals, reducing the waste at the environment in the form of leaching and runoff. The application advantage was the reduction of mechanical activities at the site (Sopper, 1993; Miyazawa et al. 1996; Nascimento et al. 2004; Hernandez et al. 1991).

Table 4 - Total and average content of heavy metals at the degraded site after high doses of sewage sludge application.

Treatments	Hg	Ba	Co	Cr	Cu	La	B	Fe	Mn
	μg kg^{-1}			mg kg^{-1}				g kg^{-1}	
0Mg ha^{-1}	<50	122.63	9.65	43.25	30.50	28.38	121.2	44.0	0.2
Mineral	< 50	123.75	11.33	42.75	29.50	28.00	174.2	43.0	0.2
60Mg ha^{-1}	< 50	185.75	13.00	43.00	29.25	27.50	158.0	41.0	0.2
120Mg ha^{-1}	50.5	121.75	8.65	40.25	31.50	30.00	107.0	38.5	0.2
240Mg ha^{-1}	150.0	132.00	8.40	42.75	35.50	37.00	60.5	39.8	0.2
	Ni	**Pb**	**Sr**	**V**	**Y**	**Zr**	**Li**	**Zn**	**Ti**
				mg kg^{-1}					
0Mg ha^{-1}	16.13	68.88	27.75	67.25	6.86	31.50	16.63	58.88 a	0.85 ab
Mineral	16.25	70.00	25.50	60.00	6.55	31.25	20.00	58.50 a	0.92 b
60Mg ha^{-1}	16.25	68.75	24.00	59.75	6.25	30.75	18.25	59.75 a	0.87 ab
120Mg ha^{-1}	15.75	71.00	23.25	57.50	6.58	22.25	17.93	67.00 ab	0.65 ab
240Mg ha^{-1}	16.25	75.00	27.00	60.25	7.10	18.25	18.00	85.00 b	0.55 a

*The concentrations of Ag, Be, Bi, Cd, Sc, Sn and W had been below the limit of the laboratory chemical analysis detection.

The concentrations of Ba, Pb, Hg, Ni and Zn in the soil (four months after the sewage sludge application) overcame the elements levels, though without reaching the alert levels of a soil considered to be clean. It would be still important to add that even though Ba was not an element monitored by IN-IAP, it was the element that got closer more proportionally to the alert level, even where there was no sewage sludge addition due to its natural concentration in the studied soil. The applied sewage sludge had around 415mg kg^{-1} of Ba and this material might raise the risks of accumulation of this element in the soil and, consequently, in the food web, as this element could be accumulated by the organisms (Company of Environmental Sanitation Technology, 2001).

It would also be important to mention that the Hg concentrations in the soil reached values below the detection limit in the laboratory analysis, being detected in two treatments, yet, not in all repetitions. The Hg level increase in the soil was proportional to the sewage sludge application (Table 4) and could be rapidly absorbed and bio accumulated by the plants and animals at all the trophic levels (Company of Environmental

Sanitation Technology, 2001; Kabata- Pendias and Pendias, 1992).

Although not the part of the heavy metals monitored by the majority of rules and regulations, it would be suitable to say that the Ti concentration found was inverse to the quantity of the sewage sludge applied (Table 4). The exposition of the soils to the effluents or emission by the industries might result them contaminated by this element; however, the Ti applied through the sewage sludge did not make environmental contamination.

The total concentrations of Zn presented significant increase between the treatments in function to the applied sewage sludge. The sewage sludge addition contributed to an increase of up to 44.4% at Zn concentrations in relation to the control. The addition of each mg kg^{-1} of Zn, increased 0.447 units in the soil. The mineral fertilization did not contribute to the addition of this element in the soil as the utilized basic fertilization without this element in the composition.

The total content of Zn found in the soil varied from 117 to 170kg ha^{-1}, therefore, was within the values established by Environmental Protection

Agency (1983) (Sopper, 1993) and with average contents in the treatments with the sewage sludge variation near to the referred concentration level proposed by CETESB, which have been usually found in the soils from Parana State (Santos Filho, 1983). According to this, even with a significant difference between the treatments, there were no limitations regarding Zn at very high doses of the sewage sludge in the soil.

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RESUMO

Obras de infra-estrutura próximas aos grandes centros levam ao surgimento de áreas degradadas por decapamento que podem ser reintegradas a paisagem através dos processos de recuperação com o uso do lodo de esgoto. Estabeleceu-se um experimento com cinco tratamentos [testemunha, três doses de lodo alcalinizado (60, 120, 240Mg ha^{-1} em base seca) e corretivo mais adubo mineral], para avaliar a recuperação imediata de uma área de empréstimo. A aplicação de lodo de esgoto alcalinizado atuou como corretivo da acidez, proporcionou aumento no teor de matéria orgânica (21 para 43,5g dm^{-3}) e P disponível (4,4 para 156mg dm^{-3}) e total, se mostrando superior ao mineral mais calagem. Mesmo com uso da maior dose, não foi observado acréscimos nos teores de 32 metais analisados, dado à baixa concentração de metais no lodo. Os resultados obtidos indicam que é possível o uso de doses elevadas de lodo de esgoto na recuperação de áreas degradadas.

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