DOI: 10.5327/Z2176-947820151914

Revista Brasileira de Ciências Ambientais

ISSN Eletrônico 2176-9478

Setembro de 2015 Nº 37

ATTRIBUTES OF DYSTROPHIC LATOSOL IN SOUTHERN MINAS GERAIS AFTER APPLICATION OF SEWAGE SLUDGE

ATRIBUTOS DE LATOSSOLO DISTRÓFICO NO SUL DE MINAS GERAIS APÓS APLICAÇÃO DE LODO DE ESGOTO

Rodrigo Santos Moreira

MSc in Ecology and Environmental Technology in Universidade Federal de Alfenas (UNIFAL-MG) – Alfenas (MG), Brazil.

Ronaldo Luiz Mincato

PhD Professor in the Graduate Program of Ecology and Environmental Technology in UNIFAL-MG – Alfenas (MG), Brazil.

Breno Régis Santos

PhD Professor in the Graduate Program of Ecology and Environmental Technology in UNIFAL-MG – Alfenas (MG), Brazil.

Rômulo Spuri Barbosa

Graduate Student in the Graduate Program of Ecology and Environmental Technology in UNIFAL-MG – Alfenas (MG), Brazil.

Adauton Vilela de Rezende

PhD Teacher at Universidade José do Rosário Vellano (UNIFENAS) – Alfenas (MG), Brazil.

Marcio Donizetti de Andrade

Chemist at Cooperativa Regional de Cafeicultores em Guaxupé LTDA (Cooxupé) – Guaxupé (MG), Brazil.

Endereço para correspondência:
Ronaldo Luiz Mincato – Rua Gabriel Monteiro da Silva, 700 – Centro – 37130-000 – Alfenas (MG), Brasil – E-mail: ronaldo.mincato@unifal-mg.edu.br

ABSTRACT

In general, tropical soils present low natural fertility, which results in a great amount of degraded areas if it is associated with improper handling. Sewage sludge, due to its high levels of organic matter and nutrients, can improve soil properties. Thus, this study evaluated the conditioning and fertilizing effects of sewage sludge on the attributes of a typical dystrophic latosol in Southern Minas Gerais. The experiment evaluated the application of sludge from Santana wastewater treatment plant in Varginhas (Minas Gerais, Brazil) in pots, with concentrations equivalent to 60, 120, and 180 t ha-1, and a control treatment without sludge. The sewage sludge has increased the levels of organic matter, cation-exchange capacity, sum of the bases and nutrients, as well as increased porosity and decreased soil density, thus indicating the potential for conditioning and fertilizing agricultural soils.

Keywords: soil fertility; organic waste; biosolids.

RESUMO

Solos tropicais, em geral, apresentam baixa fertilidade natural, e o seu manejo inadequado tem produzido uma grande quantidade de áreas degradadas. O lodo de esgoto, em função dos altos teores de matéria orgânica e nutrientes, pode melhorar as propriedades do solo. Assim, este trabalho avaliou o efeito do lodo de esgoto nas propriedades de um latossolo distrófico típico do Sul de Minas Gerais, visando o seu condicionamento e o aumento da fertilidade. O experimento estudou a aplicação de lodo da Estação de Tratamento de Esgotos de Santana em Varginha (Minas Gerais) em vasos, com doses equivalentes a 60, 120 e 180 t ha-1 de lodo e um tratamento controle sem lodo. O lodo de esgoto elevou os teores de matéria orgânica, da capacidade de troca catiônica, da soma de bases e nutrientes, além de aumentar a porosidade e diminuir a densidade aparente do solo, portanto apontando o potencial para condicionamento e fertilização de solos agrícolas.

Palavras-chave: fertilidade do solo; resíduos orgânicos; biossólidos.

INTRODUCTION

Solid residue management is one of the biggest challenges faced by Brazilian municipalities that fight environmental problems brought on from scarce investments on urban planning, public health, and environmental sanitation policies (RICCI *et al*., 2010). Sewage sludge, also called biosolid, is the residue obtained from wastewater treatment plants (WTP), and its final disposal may rise to 50% of the operational budget in a treatment system (PROSAB, 1999).

In Brazil, due to the increase in the number of WTP, the volume of sludge that demands a special final disposal has grown significantly. There has also been a significant increase in the number of WTP since the end of last century. It is in this scenery that sewage sludge disposal has become a relevant theme to the scientific community, considering the high potential of its application as a soil fertilizer in agriculture and in the recovery of downgraded soils (SUTHAR & SINGH, 2008).

Tropical soils are quite peculiar and characterized as an advanced stage of evolution, which show an adsorption complex made of low-activity clays (clays 1:1 and gibbsite), low in organic matter (OM) and with low cation exchange capacity (CEC). Therefore, they present low natural fertility (KLIEMANN *et al*., 2003). In addition, improper handling of the soils, adoption of improper agricultural and cattle-raising methods and techniques, among other actions, have resulted in fertility reduction, accelerated oxidation of the OM, and decrease of quantity and diversity of organisms in the soil (LEITE *et al*., 2010). To solve those problems, various studies have focused on the use of organic residues to improve soil properties (PIMENTEL *et al*., 2009; SANCHEZ-MONEDERO *et al*., 2004; SINGH & AGRAWAL, 2008).

Sewage sludge has high content of OM besides micro and macronutrients essential to plants, mainly N and P, improving the chemical, physical, and biological properties of the soils (CEZAR *et al*., 2012). Therefore, its use in agriculture is an appropriate alternative for final disposal, due to its low cost and for promoting the re-use of nutrients and reduction in the costs of chemical fertilizers. However, this option must follow sewage sludge characterization, because the application of sludge to the soil may imply risk of contamination of the natural ecosystems and of the trophic chain due to content of heavy metals (FJALLBORG *et al*., 2005), pathogens and toxic organic compounds, depending on wastewater properties of the sewage sludge produced in each WTP.

The tillage of agricultural soils has led to considerable increase in the content of heavy metals (BAIRD & CANN, 2011). Even so, most of the investigations carried out in the last few years show that the application of sewage sludge on soils provides benefits to agricultural production, with few environmental risks (KIDD *et al*., 2007). On the other hand, in order to use sludge safely, the *Conselho Nacional do Meio Ambiente* (CONAMA) 2006 guidelines numbers 375 and 380 established the criteria and procedures for using sewage sludge produced in WTPs in agriculture (CONAMA, 2006).

Therefore, the aim of this study was to characterize the effect of applying sewage sludge at different concentrations on physical and chemical attributes of dystrophic latosol in Southern Minas Gerais, considering its use as an agricultural fertilizer and soil conditioner.

MATERIALS AND METHODS

The experiment was conducted in the greenhouse at *Universidade José do Rosário Vellano* (UNIFENAS), in Alfenas (Minas Gerais state, Brazil), at an altitude of 880 m. Its climate is tropical mesothermic or tropical of altitude, based on Köppen's classification. Annual average temperature is around 21° to 23°C, and 1.500 mm of rainfall (ALFENAS, 2006).

For the experiment, a sample of clayey dystrophic latosol, dominant in Southern Minas Gerais, was collected from 0 to 20-cm depth at a point (21°25'S and 45°57'W) that had been manure-free for at least five years. Following collection, the soil was air-dried in the shade, broken, passed through a 4-mm-mash sieve, homogenized and, then, an aliquot was stored for routine chemical characterization following Raij *et al*. (2001). The results of analyses are shown in Table 1.

The sludge used in the experiment was produced at the Santana WTP in Varginha (Minas Gerais state), managed by Minas Gerais State Sanitation Company (COPASA). The samples representing the above WTP were collected,

Revista Brasileira de Ciências Ambientais
ISSN Eletrônico 2176-9478 Setembro de 2015 Nº 37

Table 1 - Chemical characterization of the soil used in the experiment.

pH	P	K	P-rem	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	t	T	V	m	OM
H_2O	mg dm^{-3}			cmol dm^{-3}							%		g dm^{-3}
5.6	0.5	41	7	0.6	0.4	0.0	2.1	1.1	1.1	3.2	35	0	8.1

P-rem: remaining P; SB: sum of bases; t: effective CEC; T: potential CEC; V: bases saturation; m: aluminum saturation; OM: organic matter.

systematically, top to bottom, from six drying tanks full of sludge, in February 2013. Sludge samples were dried in an oven at 65°C for three days and then ground, quartered, and stored for chemical characterization.

In order to check if the sludge met Brazilian requirements, analyses of Cd, Pb, Ni, Cr, Cu, and Zn were carried out due to the toxic potential of these elements. Samples were dissolved in *acqua regia* (MELO & SILVA, 2008) and the metals were quantified by inductively coupled plasma optical emission spectrometry (ICP-OES). The validation of metal content was done by simultaneous analyses of the certified sample of domestic sewage sludge BCR 144-R from the Belgium Institute for Reference Materials and Measurements (IRMM). The values obtained were compared to the legal limits established by CONAMA Resolutions 375 and 380 (CONAMA, 2006). Besides metals, parameters of agricultural interest were analyzed and determined content of nutrients, OM and pH, in accordance with Raij *et al*. (2001). Wetness and volatile solids were quantified by mass loss at 105 and 500° C, respectively, and total solids and inorganic elements were obtained by difference.

The experiment was carried out at random with four treatments and four repetitions, using 6 dm^3 polyethylene pots as experimental unities. Treatments with concentrations equivalent to 60, 120, and 180 t ha^{-1} of sewage sludge and a control without sludge were studied. Starting from the initial soil saturation index by bases (V%), the limestone quantity was estimated to raise V% to 70%. The dry mixture of portions of soil, limestone, and sludge was done following the adopted treatments, then it was homogenized and transferred to the pots. Next, the treated soil was incubated for 30 days, with a wetness similar to the field capacity being kept.

After incubation, a sample of approximately 0.5 dm^3 of soil was collected from each pot and a non-deformed 50 cm^3 sample with volumetric rings. Chemical attributes analyzed were the OM content, CEC, Ca^{2+}, Mg^{2+}, K^+ exchangeable content, sum of bases (SB), P, and S (CAMARGO *et al*., 2009). In addition, the physical attributes "apparent density" by the volumetric ring method and "total porosity" were determined (EMBRAPA, 1997).

The results obtained underwent variance analysis and first and second polynomial regressions by adopting the best-adjusted model. For the calculation, the statistical appliance SISVAR was used (FERREIRA, 2011), taking into consideration a 5% statistical confidence level of probability.

RESULTS AND DISCUSSION

One of the largest problems that may turn application of sewage sludge to the soil impracticable is the content of heavy metals in the residue composition. Some metals are essential elements to the plants, such as Cu, Zn, and N, called micronutrients. Others do not present a known function and are toxic, like Cd, Pb, and Cr. However, even micronutrients may be toxic to plants at high concentrations in the soil (BAIRD & CANN, 2011).

Comparison of values of the heavy metals analyzed with certified values (BCR 144-R) validated the accuracy of the conducted studies and were from 3.6 to 150 times lower than the maximum limits allowed by specific legislation (CONAMA, 2006), as seen in Table 2.

Heavy metals found in the sewage sludge are the result of, mainly, clandestine disposal of industrial effluents in the domestic draining system. Cd comes from paints, fuels, fertilizers, and pesticides, whereas Ni is from batteries, hydrogenated greases, and welds. Cr is used in tanning and electroplating processes. Cu is applied in electric wire plants, metal surface treatment, and agrotoxic industries.

Table 2 - Comparison of the content of heavy metals found in the sludge from Santana wastewater treatment plant in Varginha, and the limits established by the 2006 CONAMA Resolutions 375 and 380.

Element	Sludge*	BCR 144-R		CONAMA
		Certified	Found	
	mg dm^{-3}			
Cadmium	0.16	1.84±0.07	1.8	39
Plumb	0.3	96±1.6	98	300
Nickel	118	44.9±1.5	43	420
Chromium	0.3	90±6	94	1000
Copper	8.3	-	-	1500
Zinc	185	-	-	2800

*Average obtained from the six samples collected from the drying tanks.

At last, Zn is used in metallurgic industries (SILVA *et al*., 2001). Heavy metals can cause several problems to the food chain due to the phenomena of bioaccumulation and biomagnification (BAIRD & CANN, 2011).

Ni and Zn presented the highest content in the sludge samples, i.e. 188 and 185 mg dm^3. Such values are, respectively, 3.6 and 15 times smaller than the maximum limits allowed for the elements by the legal standards (CONAMA, 2006). The content of Cd, Pb, Cr, and Cu in the sludge was also far short from regulations, not prohibiting therefore the use of sludge in agriculture.

The sludge was also analyzed as for characteristics of agricultural interest (Table 3). For agricultural purposes, sewage sludge is considered stable if the relation between volatile soluble substances and total solids is lower than 0.70 (CONAMA, 2006). In such case, sludge presented a rate of 0.68, which is suitable for agricultural use. Nitrogen is the most important plant nutrient among organic fertilizers and the element that plants need in larger quantity. Sludge presented a 3.4% N content, which gives a great potential to supply this element to plant development. pH was near neutrality, which is ideal for soil use. It also presented a high content of OM, which makes it a choice for soil conditioning, improving its structure and the content of P, Ca, Mg, and S, despite low amounts of K, and it may favor soil fertility.

After incubation in the pots, sewage sludge provided an increased content of OM and CEC in the soil, which varied from 7.03 to 50.35 g dm^{-3} and 283.50 to 503.56 $mmol_c\,dm^{-3}$, respectively (Figures 1A and B).

The increase in OM content is the most important benefit of the agricultural use of organic residues due to its contribution to the improvement of the chemical, physical, and biological properties of soils (BERTON & VALADARES, 1991). Due to the presence of negative charges on the surface, OM is able to retain cations such as Ca^{2+}, Mg^{2+}, and K^+, as well as heavy metals. Thus, the application of sewage sludge, in addition to increasing OM content, also improves soil CEC (FERRER *et al*., 2011). In tropical and subtropical soils, negative charges of OM represent a large percentage of total CEC, as illustrated in Figure 1 and in the results obtained by Lima *et al*. (2011).

Table 3 - Agronomic characteristics of sewage sludge.

pH	P	S	Ca^{2+}	Mg^{A+}	K	N	MO	TS	VS	IS	Wetness
	mg dm^{-3}		$mmol_c\,dm^{-3}$			%	g dm^{-3}	%			
6.4	347	713	216.5	45	19.48	3.4	262.33	32.36	21.90	10.46	67.63

TS: total solids; VS: volatile solids; IS: inorganic solids.

Revista Brasileira de Ciências Ambientais
ISSN Eletrônico 2176-9478
Setembro de 2015 Nº 37

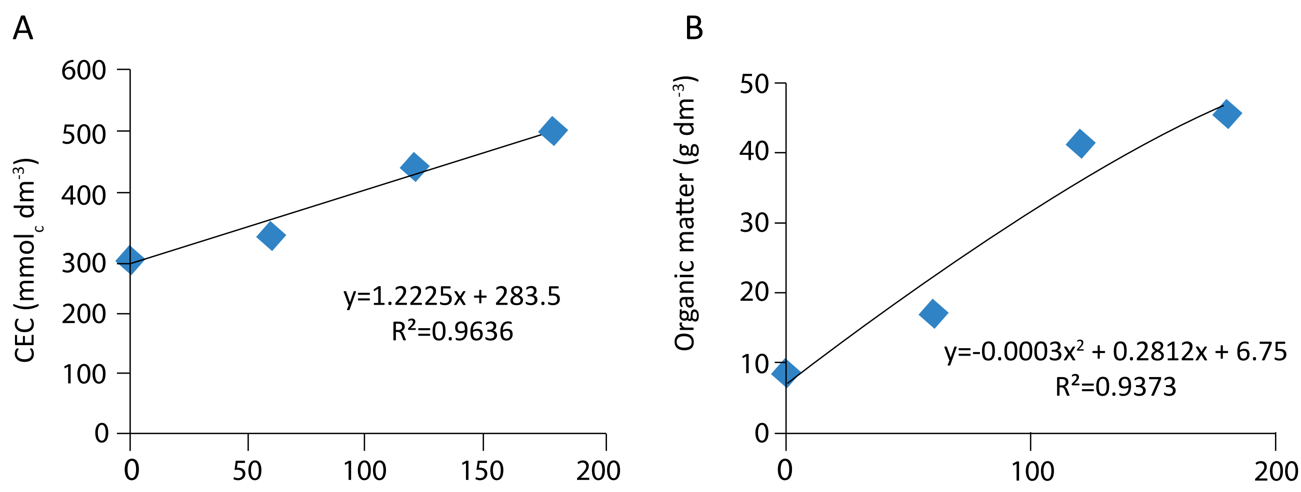

Figure 1 - Effect of the application of different sewage sludge dosages on soil CEC (A) and on organic matter (B).

Application of sludge also improves soil sorption complex in relation to K, Ca, Mg, and Na, thus increasing the SB of soils, especially when the residue is treated with limestone (FERRER *et al*., 2011). From the control to the treatment with the highest concentration of sludge, Ca increased linearly from 260.70 to 484.03 mmol$_c$ dm^{-3} (Figure 2A), and K from 1.41 to 4.42 mmol$_c$ dm^{-3}. Similarly, Mg improved from 10.75 to 17.5 mmol$_c$ dm^{-3} (Figure 2C) and the SB from 275.83 to 499.48 mmol$_c$ dm^{-3}.

Such results are in agreement with those obtained by Ricci *et al*. (2010), who observed the growth of K, Ca, and Mg content after application of up to 80 t ha^{-1}of the sewage sludge compound. The increase in content of those nutrients in the soil was continuous provided that the proportion of applied sludge was increased, which also resulted in the elevation of the SB.

As far as fertility is concerned, the evaluated sludge presented high P content (347.5 mmol$_c$ dm^{-3}) (Figure 2E). From the macronutrients required in larger quantities (N, P and K), P is the one that is requested in smallest quantities by plants, but it is the most used nutrient in fertilization in Brazil (RAIJ, 1991). This happens because plants do not absorb more than 10% of the applied P since acid tropical soils, rich in Fe and Al, retain P firmly in the soil (MALAVOLTA, 1989; SANTOS *et al*., 2008). Another point that must be considered is the scarcity of phosphate reserves to be feasibly explored in order to produce fertilizers. At current consumption rate, it is estimated that phosphate reserves are large enough for only 50 or 100 years of exploration (CORDELL *et al*., 2009). This fact makes the study of new sources of P for agriculture necessary. Variation in P content in response to the application of sludge was from 9.58 to 77.68 mg dm^{-3}, illustrating quadratic behavior (Figure 2E), which shows the high sludge potential in supplying this nutrient to plants.

The level of S in the soil also changed from 20.5 to 999 mg dm^{-3} by increasing sludge dosage (Figure 2F). This is due to the 713 mg dm^{-3} content of S in the residue (Table 3). According to Rheinheimer *et al*. (2005), soils with low OM content may present low S availability and limit plant development. Considering that the Brazilian soil, in general, presents low OM content, the addition of residues with high organic content as sewage sludge may also be important to supply S to plants. The origin of S in sewage sludge is attributed to the decomposition of proteins from human feces, to the presence of surfactants, and to S derived from the burning of fossil fuels (SÍGOLO & PINHEIRO, 2010).

Significant differences were observed among treatments and in the physical characteristics of apparent density and porosity of the soil. The results are in agreement with those of Aggelides & Londra (2000), for whom the application of sewage sludge supplies OM, which improves the particle aggregation condition, and, in turn, decreases density and increases soil porosity.

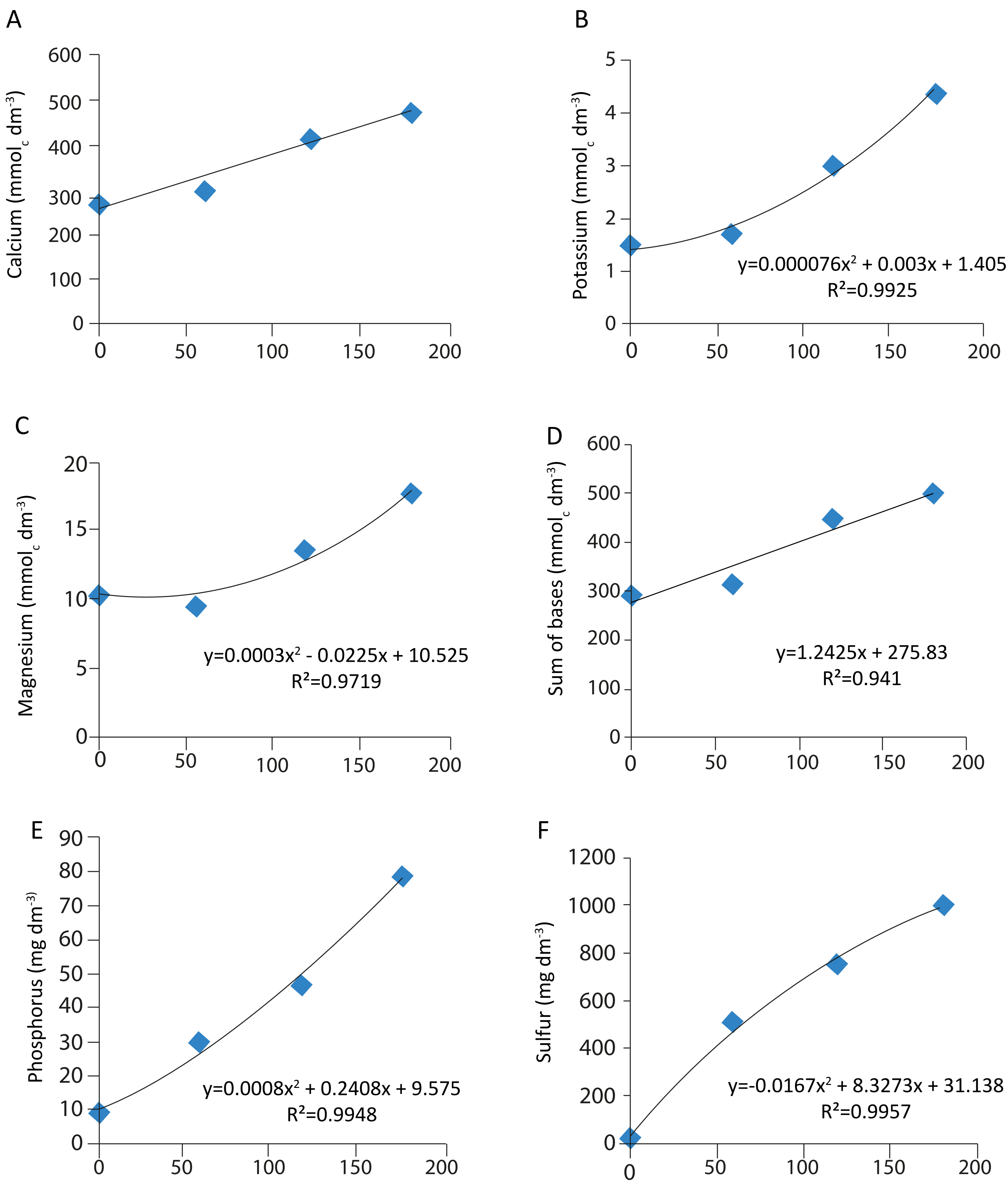

Figure 2 - Effect of the application of different sewage sludge dosages on Ca, K, Mg, P, S content and on the soil of sum of bases.

In accordance with the regression equations, the decrease in density and the increase in porosity occurred linearly by making the dosage of applied sludge higher, which varied from 1.38 to 1.06 g cm-3 and 42.38 to 63.73%, respectively (Figures 3A and 3B). The lowest density and highest porosity values provide the expectation of an increase in water infiltration in soil, and, consequently, less surface draining, which decreases erosion and offers more favorable conditions for the development of plants.

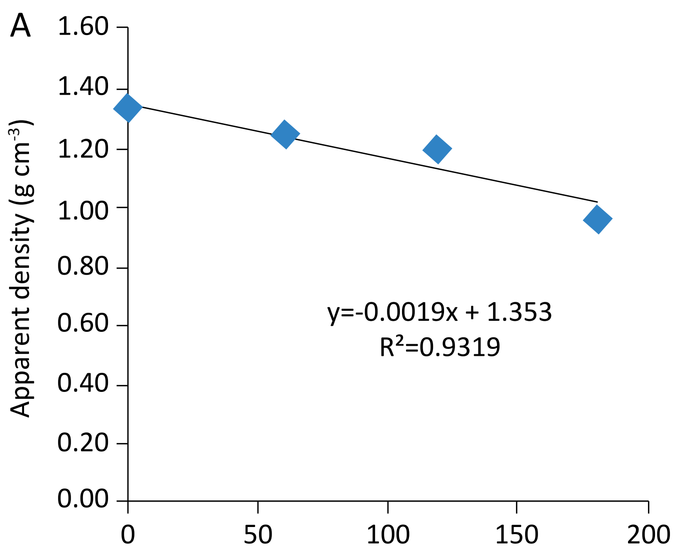

Figure 3 - Effect of the application of different sewage sludge dosages on apparent density (A) and total porosity (B) of the soil.

CONCLUSIONS

Results indicate that the application of sewage sludge increased P, K, Ca, Mg, and S content, SB, CEC and OM, leading to a significant improvement in the fertility of the dystrophic latosol prevalent in Southern Minas Gerais. In fact, sewage sludge contributed even more to decrease the apparent density and to increase total porosity, improving physical properties of the studied latosol. The results suggest that the sewage sludge from the Santana treatment plant in Varginha, Minas Gerais, presents favorable conditions to be used as agricultural fertilizer and soil conditioner.

ACKNOWLEDGEMENTS

To COPASA for providing the sewage sludge samples and to COOXUPE for the chemical analysis.

REFERENCES

AGGELIDES, S. M.; LONDRA, P. A. Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and clay soil. *Bioresource Technology*, Amsterdam, v. 71, n. 3, p. 253-259, 2000.

ALFENAS. *Leitura Técnica do Plano Diretor de Alfenas – MG*. Alfenas: Prefeitura Municipal de Alfenas, 2006. 189p.

BAIRD, C.; CANN, M. *Química ambiental*. 4. ed. Porto Alegre: Bookman, 2011. 844p.

BERTON, R. S.; VALADARES, J. M. A. S. Potencial agrícola de composto de lixo urbano no Estado de São Paulo. *O Agronômico*, v. 43, n. 2, p. 87-93, 1991.

CAMARGO, O. A.; MONIZ, A. C.; JORGE, J. A.; VALADARES, J. M. A. S. *Métodos de análises química, mineralógica e física dos solos do Instituto Agronômico de Campinas*. Boletim Técnico 106. Campinas: Instituto Agronômico de Campinas, 2009. 77p.

CEZAR, R.; SILVA, M.; COLONESE, J.; BIDONE, E.; EGLER, S.; CASTILHOS, Z.; POLIVANOV, H. Influence of the properties of tropical soils in the toxicity and bioavailability of heavy metals in sewage sludge-amended lands. *Environmental Earth Science*, Berlin, v. 66, n. 8, p. 2281-2292, 2012.

CONAMA – Conselho Nacional do Meio Ambiente. *Resoluções 375 e 380, de 29 de agosto de 2006*. Disponível em: <http://www.mma.gov.br/port/conama/res06/res37506.pdf>. Acesso em: 01 jul. 2010.

CORDELL, D.; DRANGERT, J. O.; WHITE, S. The story of phosphorus: global food security and food for thought. *Global Environmental Change*, v. 19, n. 2, p. 292-305, 2009.

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Centro Nacional de pesquisas do solo. *Manual de Métodos de Análise de Solo*. 2. ed. Rio de Janeiro: EMBRAPA, 1997.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, Lavras, v. 35, n. 6, p. 1039-1042, 2011.

FERRER, A.; DE OÑA, J.; OSORIO, F.; MOCHÓN, I. Evolution of the soil and vegetation cover on road embankments after the application of sewage sludge. *Water Air Soil Pollution*, Berlin, v. 214, n. 1, p. 231-240, 2011.

FJALLBORG, B.; AHLBERG, G.; NILSSON, E.; DAVE, G. Identification of metal toxicity in sewage sludge leachate. *Environment International*, Elmsford, v. 31, n. 1, p. 25-31, 2005.

KIDD, P. S.; DOMÍNGUEZ-RODRÍGUEZ, M. J.; DÍEZ, J.; MONTERROSO, C. Bioavailability and plant accumulation of heavy metals and phosphorus in agricultural soils amended by long-term application of sewage sludge. *Chemosphere*, Amsterdam, v. 66, n. 8, p. 1458-1467, 2007.

KLIEMANN, H. J.; MAGALHÃES, R .T.; OLIVEIRA, I. P.; MORAES, M. F. Relações da produção de massa verde de *brachiaria brizantha* com os índices de disponibilidade de nutrientes em solos sob o sistema barreirão de manejo. *Pesquisa Agropecuária Tropical*, Goiânia, v. 33, n. 1, p. 49-56, 2003.

LEITE, L. F. C.; OLIVEIRA, F. C.; ARAUJO, A. S. F.; GALVÃO, S. R. S.; LEMOS, J. O.; SILVA, E. F. L. Soil organic carbon and biological indicators in an Acrisol under tillage systems and organic management in north-eastern Brazil. *Australian Journal of Soil Research*, Sidney, v. 48, n. 3, p. 258-265, 2010.

LIMA, R. L. S.; SEVERINO, L. S., SOFIATTI, V.; GHEYI, H. R.; ARRIEL N. H. C. Atributos químicos de substrato de composto de lixo orgânico. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 15, n. 2, p. 185-192, 2011.

MALAVOLTA, E. *ABC da adubação*. São Paulo: Agronômica Ceres, 1989. 292p.

MELO, L. C. A.; SILVA, C. A. Influência de métodos de digestão e massa de amostra na recuperação de nutrientes em resíduos orgânicos. *Química Nova*, São Paulo, v. 31, n. 3, p. 556-561, 2008.

PIMENTEL, M. S.; DE-POLLI, H.; LANA, A. M. Q. Atributos químicos do solo utilizando composto orgânico em consórcio de alface-cenoura. *Pesquisa Agropecuária Tropical*, Goiânia, v. 39, n. 3, p. 225-232, 2009.

PROSAB – Programa de Pesquisa em Saneamento Básico. *Uso e manejo de lodo de esgoto na agricultura*. Rio de Janeiro: PROSAB, 1999. 97p.

RAIJ, B. VAN.; ANDRADE, J. C.; CANTARELLA, H.; QUAGGIO, J. A. (ed.). *Análises químicas para avaliação da fertilidade de solos tropicais*. Campinas: Instituto Agronômico, 2001. 285p.

RAIJ, B. van. *Fertilidade do solo e adubação*. Piracicaba: Agronômica Ceres, Associação Brasileira para Pesquisa da Potassa e do Fosfato, 1991. 343p.

RHEINHEIMER, D. S.; ALVAREZ, J. W. R.; FILHO, B. D. S.; SILVA, L. S.; BORTOLUZZI, E. C. Resposta de culturas à aplicação de enxofre e a teores de sulfato num solo de textura arenosa sob plantio direto. *Ciência Rural*, Santa Maria, v. 35, n. 3, p. 562-569, 2005.

RICCI, A. B.; PADOVANI, V. C. R.; DE PAULA, D. R. J. Uso de lodo de esgoto estabilizado em um solo decapitado. II – Atributos químicos e revegetação. *Revista Brasileira de Ciência do Solo*, Viçosa, v. 34, n. 2, p. 543-551, 2010.

SANCHEZ-MONEDERO, M. A.; MONDINI, C.; DE NOBILI, M.; LEITA, L.; ROIG, A. Land application of biosolids. Soil response to different stabilization degree or treated organic matter. *Waste Management*, Amsterdam, v. 24, n. 4, p. 325-332, 2004.

SANTOS, J. Z. L.; FURTINI NETO, A. E.; DE RESENDE, A. V.; CURI, N.; CARNEIRO, L. F.; COSTA, S. E. V. G. A. Frações de fósforo em solo adubado com fosfatos em diferentes modos de aplicação e cultivado com milho. *Revista Brasileira de Ciência do Solo*, Viçosa, v. 32, n. 3, p. 705-714, 2008.

SÍGOLO, J. B.; PINHEIRO, C. H. R. Lodo de esgoto da ETE Barueri – SP: Proveniência do enxofre elementar e correlações com metais pesados associados. *Geologia USP*, Série Científica, São Paulo, v. 10, n. 1, p. 39-51, 2010.

SILVA, F. C.; BOARETTO, A. E.; BERTON, R. S.; ZOTELLI, H. B.; PEXE, C. A.; BERNARDES, E. M. 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.

SINGH, R. P.; AGRAWAL, M. M. Potential benefits and risks of land application of sewage sludge. *Waste Management*, Amsterdam, v. 28, n. 2, p. 347-358, 2008.

SUTHAR, S.; SINGH, S. Bioconcentrations of metals (Fe, Cu, Zn, Pb) in earthworms (Eisenia fetida), inoculated in municipal sewage sludge: do earthworms pose a possible risk of terrestrial food chain contamination? *Ecotoxicology Environmental Safety*, Amsterdam, v. 24, n. 1, p. 25-32, 2008.