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NUTRIENTS AND HEAVY METALS IN MAIZE CROP FERTILIZED WITH ROCK PHOSPHATE AND BIOSOLID

Márcio Neves Rodrigues[1], Regynaldo Arruda Sampaio[2], Geraldo Ribeiro Zuba Junio[3] & Agda Loureiro Gonçalves Oliveira[4]

[1] Biólogo, UFMG/ Montes Claros- MG, marcionrodrigues@gmail.com
[2] Engenheiro Agrônomo, Professor Titular da UFMG/Montes Claros-MG, rsampaio@ica.ufmg.br
[3] Engenheiro Agrônomo, UFMG/Montes Claros-MG, juniozuba@yahoo.com.br
[4] Estudante de Engenharia Agrícola e Ambiental, UFMG/Montes Claros-MG, agdaloureiro@gmail.com

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ABSTRACT

This study aimed to evaluate effects of natural phosphate and sewage sludge compound fertilization in level of contents of heavy metals and nutrients in two consecutive cultivation of corn grain. The project was conducted in a Haplic Cambisol between April 10, 2009 and September 15, 2010. The treatments in factorial scale 2 x 4 meters corresponds to application on the first corn cultivation of 2 doses of rock Gafsa phosphate (0 and 90 kg ha^{-1} of P_2O_5) and 4 compound doses of sewage sludge (0, 25, 50 and 75 t ha^{-1}, in dry specimen). The experiment followed random blocks design with three treatment repetitions. The fertilization with rock phosphate increased the levels of N, P, K and Mg only in the first corn grain cultivation and did not had influence on the levels of Zn, Cu, Ni, Pb, Cr and Cd in the two successive cultivations. The fertilization with sewage sludge compound increased the levels of N, P, K, Mg and Zn in the first corn grain cultivation and P and Zn for the second. In addition, the fertilization with sewage sludge did not had influence on levels of Ca, S, Cu, Ni and Pb in any corn cultivation. Independent of the effect of the treatments, only Pb showed concentration above of acceptable limits for nourishment.

Palavras-chave:
adubação orgânica
lodo de esgoto
poluição do solo

NUTRIENTES E METAIS PESADOS EM CULTIVO DE MILHO FERTILIZADO COM FOSFATO DE ROCHA E BIOSÓLIDO

RESUMO

O objetivo deste trabalho foi avaliar o efeito da adubação com fosfato natural e composto de lodo de esgoto sobre os teores de nutrientes e metais pesados em grãos de milho em dois cultivos consecutivos. O trabalho foi conduzido em Cambissolo Háplico, no período de 10 de abril de 2009 a 15 de setembro de 2010. Os tratamentos, em esquema fatorial 2 x 4, corresponderam a aplicação no primeiro cultivo de milho de 2 doses de fosfato natural de gafsa (0 e 90 kg ha^{-1} de P_2O_5) e 4 doses de composto de lodo de esgoto (0, 25, 50 e 75 t ha^{-1}, em base seca). O delineamento experimental utilizado foi em blocos casualizados, com 3 repetições dos tratamentos. A adubação com fosfato natural aumentou os teores de N, P, K e Mg nos grãos de milho apenas no primeiro cultivo e não influenciou os teores de Zn, Cu, Ni, Pb, Cr e Cd nos dois cultivos sucessivos. A adubação com composto de lodo de esgoto aumentou os teores de N, P, K, Mg e Zn nos grãos de milho no primeiro cultivo e de P e Zn no segundo cultivo e não influenciou os teores de Ca, S, Cu, Ni e Pb em nenhum dos cultivos. Independente do efeito dos tratamentos, apenas o Pb apresentou concentração acima dos limites toleráveis para alimentação.

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INTRODUCTION

Increasing implantation of Wastewater Treatment Plant, attending to legal environmental recommendations for remediation of lakes and fountains and reduction of heath public problems, has been creating residues like sewage sludge (VON SPERLING, 2003). This is a relevant fact if counting the final disposal of this material, which can generate serious environmental harm becoming global concern (BIONDI & NASCIMENTO, 2005 & LEMAINSKI; SILVA, 2006a). Its inadequate destination can represent risks to human health and to the ecosystem due to toxic organic compounds (USMAN, 2012) and also to groundwater due to contamination by heavy metals (NASON, 2014).

Therefore, a solution is necessary to deposit this residue, and agricultural recycling is a promising solution, considering all the relevant points of its formation. In order to follow the CONAMA 375/2006 resolution Martins *et al*. (2003), Silva *et al*. (2005), Gomes *et al*. (2006) and Barbosa *et al*. (2007) point out the economy and environmental benefits of applying this material on the productive systems. The usage of the sewage sludge in a variety of crops is a worldwide trend (MARQUES *et al*., 2007), and this procedure stands out in Brazil during experiments with coffee (BETTIOL & CAMARGO, 2000), sugarcane (CHIBA et *al*., 2008a), eucalyptus crops (ANDRADE & MATTIAZZO, 2000), soybean (VIEIRA *et al*., 2005; LEMAINSKI; SILVA, 2006b), and corn (NASCIMENTO *et al.*, 2004; TRANNIN *et al.*, 2005; NOGUEIRA *et al*., 2007).

The exploitation of sewage sludge on agriculture also contributes to reduction of chemical fertilizers, to save natural resources and to reduce production cost. Sewage sludge is an important source of organic matter and essential elements to plants (LEMAINSKI & SILVA, 2006a), promoting physic and chemical improvements in the soil (MARQUES *et al*., 2002; TSUTIYA *et al*., 2002; SILVA *et al*., 2005). Also, sewage sludge and can also be used for silviculture, floriculture, landscaping or recovering degraded areas.

The amount of sewage sludge to be applied in the soil can be measured based on nitrogen levels present in the sludge and according to the requirements of the plant to be cultivated (ZUBA JUNIO *et al*., 2011), however, attention should be paid on levels of contaminants, such as persistent organic matter, microorganisms and heavy metals. In the long-term, the increase of soil metal concentration, resulting from successive application without adequate control, can contaminate the environment (NASCIMENTO *et al*., 2004; GOMES *et al*., 2006). The soil and plants contamination by heavy metals can restrict the usage of sewage sludge as a fertilizer (GOMES *et al*., 2006; NOGUEIRA *et al*., 2007; OLIVEIRA *et al*., 2009).

Increased levels of heavy metals such as Cu, Pb and Zn due to sludge utilization on soils cultivated with corn were found by Galdos *et al.* (2004), Silva *et al.* (2006) and Zuba Junio *et al.* (2011). Marques *et al.* (2007) also found increasing levels of heavy metals in sugar cane crops fertilized with sewage sludge. Nevertheless, Chiba *et al*. (2008b) used this same plant and did not find increase in Cu and Zn levels available on the soil, but rather levels below permitted by environmental law (policy). Several projects show that although fertilization with sewage sludge on corn crop permitted growth even in presence heavy metals, these remain within the levels established by law (RANGEL *et al*., 2004; GOMES *et al*., 2006; NOGUEIRA *et al*., 2007; ZUBA JUNIO *et al*., 2011).

According to CONAMA Resolution 375, corn culture is considered adequate for sewage sludge fertilization due to its characteristics and the fact that Brazil is one of the biggest global producer of corn, alongside China and the United States (RANUM *et al*., 2014). Sewage sludge usage in corn cultivation can serve as a satisfactory alternative in environmental and economic aspects.

The intense use of phosphate fertilizers in agriculture is justified by low availability of phosphorus in the soil, especially in Brazil, frequently limiting productivity of some crops (FREITAS *et al.*, 2009). Furthermore, there is low efficiency on phosphorus absorption by crops and high fixation rate of this element in the majority of soils, increasing necessity of compost application containing this element in agriculture soils. These facts could lead to contamination since these fertilizers consist of a gateway for heavy metal introduction in the soil (CAMPOS *et al.*, 2005; FREITAS *et al.*, 2009).

As stated, this study has as main objective evaluate nutrient and heavy metals presence in corn grains fertilized with sewage sludge and reactive natural phosphate in two successive cultivation.

MATERIALS AND METHODS

The experiment was conducted in an experimental area of the Federal University of Minas Gerais in Montes Claros – MG; with latitude of 16º51'38" S and longitude 44º55'00" W. Haplic Cambisol composes the area with chemical and physical characteristics of layer 0-20 cm listed in Table 1, according to Embrapa's methodology (EMBRAPA, 1997). Corn (*Zea mays*) variety BR 106 was grown in two successive cultivations.

The treatments arranged in factorial 2 x 4 corresponded to 2 distinct doses of phosphate rock (0 and 90 ha^{-1} of P_2O_5) combined with 4 different doses of sewage sludge (0, 25, 50 and 75 t ha^{-1}, in dry basis) with three repetitions following randomized block design. The Gafsa reactive phosphate rock used has the following chemical characteristics: P_2O_5 total = 29.00 %; P_2O_5 soluble in citric acid at 2 % relation 1:100 = 10.00 %; P_2O_5 soluble in formic acid at 2 %, relation 1:100 = 21.00 %; SO_3 = 3.20 %; SiO_2 = 3.6 %; Ca = 32.00 %; MgO = 0.80 %; K_2O = 0.11 % and heavy metals level presented on Table 2. Calculations to applied dose were based on level of available phosphorus on the soil and on recommendations made by Noce (2004) for corn BR 106 variety. Doses of sewage sludge were based on nitrogen concentration in this fertilizer and recommendations made by Noce (2004) for corn BR 106 (80 kg ha^{-1} of N).

The dehydrated sewage sludge was collected at a wastewater treatment plant located in Juramento – MG. The wastewater treatment plant is operated by COPASA-MG and has the capacity to treat 217 m^3 of sludge per day. The treatment line is composed by a preliminary treatment and a UASB reactor, which is connected in series to a pond as an optional treatment. The sludge generated in a UASB reactor was dehydrated in a drying bed and subsequently disposed in a controlled landfill, which was implanted at the station area. The sewage sludge chemical characteristics are described in Table 2.

The composting was made by mixing of sewage sludge and bean straw in which presented characteristics described on Table 2. Mixing was made in order to achieve the C/N relation of 30/1 using three parts of bean straw for one of sludge and conducted by pallets approximately 1.5m high. Temperature and humidity were monitored daily. The systematic manual mixing of pallets using shovel and hoe is used to control participating factors on the process.

The fertilizer was applied using Gafsa phosphate rock and sewage sludge compound on furrows corresponding to each treatment. Row spacing for corn crop was 80 cm with crop of 5 seeds by linear meter (expected performance of fifty thousand of plants by hectare). The parcel size is equivalent to 6 x 4.8 m. The four central rows of 4 m in length were harvested whereas the two peripheral rows and 1 m at the end of the the borders were eliminated.

The second cultivation was made 30 days after the first harvest, manual weeding, and stubble deposition on the respective parcel and furrowing areas with hoes. Grooves were made on the planting lines for seed distribution during the first cultivation. The culture had been maintained cline throughout the cycle. The irrigation method used was by sprinkler irrigation system. After harvest, the grains were analyzed on levels of N, P, K, Ca, Mg, S, Cu, Zn, Ni, Cd, Cr, and Pb as methodology proposed by Tedesco *et al.* (1995).

The data collected were subjected to variance analysis, whereas the average for phosphate doses was tested by Tukey test with 5% probability. Sewage sludge doses average, adjusted to regression model, was tested by t-test with 10% probability.

Table 1. Chemical and physical soil attributes of experimental area at profundity from 0 -20 cm

Chemical Attributes													
pH	P rem.	P	K	Ca	Mg	Al	SB	H + Al	t	T	m	V	MO
5.5	.... $mg.kg^{-1}$			.... $cmolc.dm^{-3}$							.... %		
	37.5	3.2	67	3.1	1.1	0.50	4.37	4.94	4.87	9.31	10	47	1.09

Micronutrients and heavy metals					
Zn	Cu	Pb	Cd	Ni	Cr
.... $mg\ dm^{-3}$					
1.32	1.27	11.64	0.09	3.93	0.0

Physical Attributes		
Sand	Silt	Clay
.... $dag.kg^{-1}$		
38.00	30.00	32.00

Source: Elaborated by the autor

dag kg^{-1} = % (m/m); cmolc dm^{-3} = meq 100 cm^{-3}; M.O. = 1.724 x C.O; SB = Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}.

t = SB + Al^{3+}. T = SB + (H + Al). m = 100 Al^{3+}/t. V = 100 SB/T.

Analytic Methodology: EMBRAPA (1997).

Table 2. Chemical characteristics of rock phosphate (FN), bean straw (PF), sewage sludge (LE) and compost of sewage sludge (CLE).

	N	P	K	Ca	Mg	S	Zn	Cu	Cd	Pb	Cr	Ni
	---------------- $g\ kg^{-1}$ ----------------						---------------- $mg\ dm^{-3}$ ----------------					
FN	-	-	-	-	-	-	266.0	11.0	16.8	156.5	734.2	143.0
PF	0.91	0.12	2.00	1.2	0.40	0.04	16.0	2.5	0.0	40.0	0.00	1.0
LE	1.77	0.41	0.66	0.05	0.22	1.24	162.3	90.0	1.1	162.0	788.0	105.7
CLE	1.63	0.42	0.68	0.40	0.22	1.26	304.3	81.7	1.2	168.0	800.0	97.0

Inorganic substances, Maximum concentration permitted on sewage sludge or derivate product (mg kg^{-1}, base seca): Zinc: 2,800, Copper: 1,500, Cadmium: 39, Lead: 300, Chromium: 1.000 Nickel: 420, CONAMA (2006).

Analytic methodology: Tedesco *et al*. (1995).

RESULTS AND DISCUSSION

Analysis of variance revealed that there was no interaction between reactive phosphate rock and sewage sludge compound in relation to nutrient levels and heavy metals in corn grains as shown in Table 3.

According to Table 4, the application of phosphate rock increased the N levels in corn grains for the first cultivation. On the other hand, the same effect was not found for the second cultivation. Considering nitrogen absorption process by plants depends on energy from ATP (SOUZA & FERNANDES, 2006), the major P availability by application of phosphate rock could have contributed for bigger absorption of N, which caused increase on levels of this element in grains. Araújo and Machado (2006) state the existent synergism between N and P, and, thus, emphasize the importance of P on photosynthetic reactions and on C metabolism processes, which are fundamentals for N assimilation.

Table 3. Summary of the analysis of variance for nutrients and heavy metals in corn grain in soil fertilized with sewage sludge and reactive rock phosphate.

Nutrients							
FV	**GL**	**QM**					
		N	**P**	**K**	**Ca**	**Mg**	**S**
BL	2	0.0074^{ns}	0.011^{ns}	0.011^{ns}	0.026*	0.001^{ns}	0.0005^{ns}
DP	1	0.057*	0.068**	0.042**	0.007^{ns}	0.013**	0.0002^{ns}
DL	3	0.036^{ns}	0.022*	0.019*	0.001^{ns}	0.007*	0.0002^{ns}
DP x DL	3	0.0080^{ns}	0.008^{ns}	0.007^{ns}	0.0002^{ns}	0.0005^{ns}	0.00003^{ns}
ERROR	14	0.011 ^{ns}	0.005^{ns}	0.004^{ns}	0.004^{ns}	0.001^{ns}	0.0002^{ns}
TOTAL	23						

Heavy metals					
		QM			
		Zn	**Cu**	**Ni**	**Pb**
BL	2	29.6^{ns}	0.29^{ns}	2.4176e-33^{ns}	123.338^{ns}
DP	1	170.6^{ns}	0.38^{ns}	2.4176e-33^{ns}	48.792^{ns}
DL	3	230.8*	0.71^{ns}	2.4176e-33^{ns}	72.617^{ns}
DP x DL	3	27.7^{ns}	0.38^{ns}	2.4176e-33^{ns}	64.663^{ns}
ERROR	14	46.3^{ns}	0.34^{ns}	2.4176e-33^{ns}	55.144^{ns}
TOTAL	23				

* Significant at 5% probability and ** Significant at 1% probability, respectively, by t-test

^{ns} Not Significant

In the same way as N, the P levels in corn grains were positively affected by phosphate rock application for the first cultivation (Table 4). However, phosphate absorption did not have effect on this element for the second cultivation. Machado *et al.* (2001) also reported increase on levels of P in corn grains in response to phosphate fertilizer. Thus, this highlights corn capacity to store P in grains given the bigger availability of the element in the soil.

The levels of K and Mg in corn grain also increased with phosphate rock application on the soil during the first cultivation (Table 4).

This increase of K and Mg in corn grains can be assigned to phosphate composition that present such elements. Although present on phosphate rock differences in levels of Ca and S on corn grain were not diagnosed for the first cultivation as well as K, Mg and S for the second cultivation. In addition were not detected levels of Ca on the second cultivation.

In relation to heavy metals, the presence of Cd and Cr was not detected in corn grains. As for the other elements that had not been observed, there was an increase in Cu, Zn, Ni, and Pb levels in corn grains due to phosphate application in the first and second cultivation (Table 5). Although these elements have been detected in phosphate rock, literature also mentions, systematically, that levels of heavy metals increase when phosphate fertilizers are applied (CAMPOS *et al*., 2005; FREITAS *et al.,* 2009).

Reduction of nutrient levels in corn grain was observed when comparing the first and second crop (Table 4 and 5), mainly on Ca and Zn minerals. Such fact may have occurred due to nutrient exportation in the first crop besides nutrient loss by leaching. Concerning Ni, there was an increase in concentration for both the first and second crop. As

Table 4. Nutrient levels in corn grains in function of fertilization with phosphate rock and sewage sludge compound in two successive cultivation

Variable	P_2O_5 Dose (kg ha^{-1})	Doses of sewage sludge compound (t ha^{-1}) 0	25	50	75	Average
1º Corn Crop						
N (dag kg^{-1})	0	1.28	1.40	1.43	1.48	1.40b
	90	1.46	1.41	1.50	1.61	1.50a
	Average	1.37	1.41	1.47	1.55	-
P (dag kg^{-1})	0	0.42	0.53	0.51	0.66	0.53b
	90	0.62	0.62	0.63	0.68	0.64a
	Average	0.52	0.58	0.57	0.67	-
K (dag kg^{-1})	0	0.47	0.64	0.53	0.64	0.57b
	90	0.63	0.64	0.64	0.71	0.66a
	Average	0.55	0.64	0.59	0.68	-
Ca (dag kg^{-1})	0	0.2	0.19	0.18	0.22	0.20a
	90	0.23	0.24	0.22	0.24	0.23a
	Average	0.22	0.22	0.20	0.23	-
Mg (dag kg^{-1})	0	0.13	0.19	0.16	0.22	0.18b
	90	0.19	0.22	0.23	0.26	0.23a
	Average	0.16	0.21	0.20	0.24	-
S (dag kg^{-1})	0	0.1	0.11	0.11	0.11	0.11a
	90	0.1	0.11	0.11	0.12	0.11a
	Average	0.10	0.11	0.11	0.12	-
2º Corn Crop						
N (dag kg^{-1})	0	1.42	1.25	1.37	1.41	1.36a
	90	1.27	1.37	1.44	1.38	1.37a
	Average	1.35	1.31	1.41	1.40	-
P (dag kg^{-1})	0	0.33	0.38	0.44	0.46	0.41a
	90	0.38	0.45	0.49	0.41	0.43a
	Average	0.36	0.42	0.47	0.44	-
K (dag kg^{-1})	0	0.39	0.41	0.43	0.45	0.42a
	90	0.44	0.48	0.48	0.43	0.46a
	Average	0.42	0.45	0.46	0.44	-
Mg (dag kg^{-1})	0	0.14	0.15	0.16	0.17	0.16a
	90	0.15	0.17	0.20	0.15	0.17a
	Average	0.15	0.16	0.18	0.16	-
S (dag kg^{-1})	0	0.10	0.11	0.10	0.10	0.10a
	90	0.11	0.10	0.10	0.18	0.12a
	Average	0.11	0.11	0.10	0.14	-

To each variable, average followed by same vertical lower case did not differ statistically, up to 5% probability, by Tukey test.

Table 5. Heavy metals level in corn grain in function of fertilization with phosphate and sewage sludge compound in two successive cultivation

Variable	P_2O_5 Dose (kg ha^{-1})	Doses of sewage sludge (t ha^{-1})				Average
		0	25	50	75	
1º Corn Crop						
Zn (mg kg^{-1})	0	21.67	33.67	27.33	39.67	30.59a
	90	32.00	37.33	34.33	43.33	36.55a
	Average	26.84	35.50	30.83	41.50	-
Cu (mg kg^{-1})	0	1.67	2	1.67	2	1.84a
	90	1.33	2	2.33	2.67	2.08a
	Average	1.50	2.00	2.00	2.34	-
Pb (mg kg^{-1})	0	15.71	25.48	30.37	25.48	24.26a
	90	20.60	25.48	20.60	18.97	21.41a
	Average	18.16	25.48	25.49	22.23	-
2º Corn Crop						
Zn (mg kg^{-1})	0	8.67	15.67	25.00	27.00	19.09a
	90	17.67	26.67	29.00	21.67	23.75a
	Média	13.17	21.14	27.00	24.34	-
Cu (dag kg^{-1})	0	1.00	1.00	1.00	1.00	1.00a
	90	1.00	1.33	1.67	1.00	1.25a
	Média	1.00	1.17	1.34	1.00	-
Pb (dag kg^{-1})	0	29.33	21.33	24.67	21.33	24.17a
	90	23.67	24.67	25.00	22.67	24.00a
	Média	26.50	23.00	24.84	22.00	-

To each variable, average followed by same vertical lower case did not differ statistically, up to 5% probability, by Tukey test.

for Pb, the values were kept approximately at the same levels on both crops, highlighting significant residual effect of these elements on soil.

On Figure 1, N levels were observed to have increased in corn grains for the first crop with the increment sewage sludge, reaching the maximum value of 1,56 dag kg^{-1} with the biggest applied dose. The obtained values in this experiment were approximately in accordance to results found by Vyn & Tollenaar (1998). They found levels of N varying from 1.41 to 1.76 dag kg^{-1} using corn grains from 6 different varieties in 2 crop densities. Nitrogen is one of the major elements in sewage sludge (GOMES *et al*., 2006; RANGEL *et al.,* 2006) and, since it is linked mainly with organic compound, its liberation is gradual. However, in this experiment, after one year of sewage sludge application on the soil, effects of the increase in doses on N levels could not be found in corn grain, being the average values 1.37 dag kg-1.

The application of rising doses of sewage sludge promoted increment on phosphorous levels in corn grains for the first crop (Figure 1), reaching maximum of 0.66 dag kg^{-1} with a dose of 75 t ha^{-1} and on second crop, reaching the maximum of 0.47 dag kg^{-1} with the same dose of sludge compound. One notices that because of nutrient exportation in the first crop, there was a reduction on the maximum concentration of P in the second crop. Even so, the values were below from those found by Vyn & Tollenaar (1998), which fluctuated between 0.25 and 0.30 dag kg^{-1} in grains for 6 different varieties of corn.

There was an increase of K and Mg levels, for the first crop, with the increment of the sewage sludge doses applied, reaching maximum of 0.66 dag kg^{-1} and 0,24 dag kg^{-1}, respectively, with the application of 75 t ha^{-1} sewage sludge. In the second cultivation, there was no influence found between the sewage sludge and K and Mg levels, being that K level was 0.44 dag kg^{-1} and Mg 0.16 dag kg^{-1}. In other words, these concentrations lower than the ones found in the first crop. These values of K and Mg are in accordance to USDA for corn grain, which are 0.29 dag kg^{-1} for potassium and 0.13 dag kg^{-1} for magnesium.

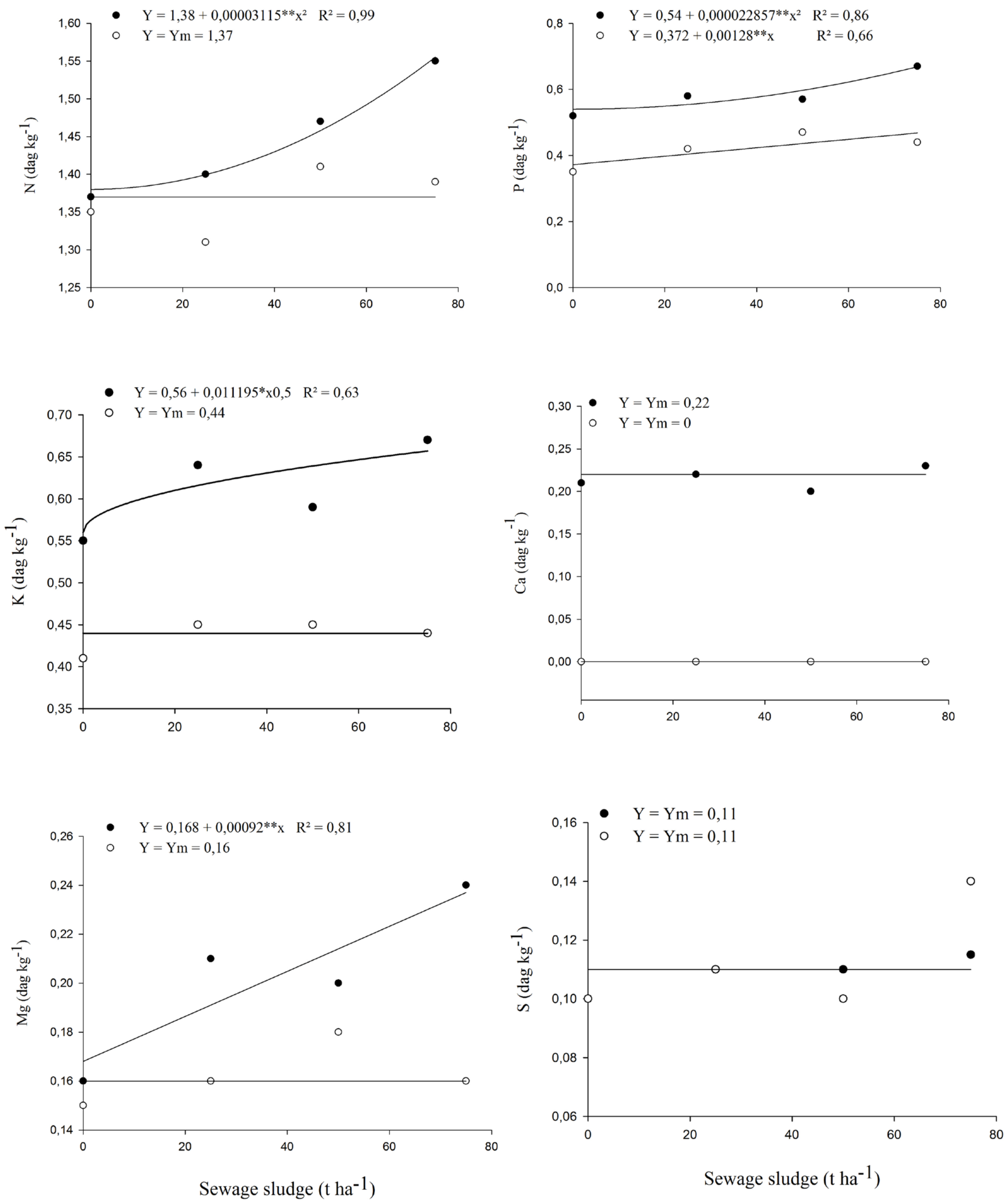

Figure 1. Graphics showing the regression equations linking nutrient levels in corn seeds with applied doses of sewage sludge

The average values of Ca were: 0.22 dag kg^{-1} in the first crop and 0.0 dag kg^{-1} in the second crop. The first crop values were above the values presented by FAO for this element in corn grain, which is 0.05 dag kg^{-1}. For S, both in the first and in the second crop (0.11 dag kg^{-1}), the values are close to the one cited by Mengel & Kirkby (1987), which is 0.17 dag kg^{-1}, considered ideal for corn. It is observed, therefore, sludge residual effect as for S levels and no residual effect as for Ca levels.

In Figure 2, sewage sludge application on the soil can be seen to result an increase of Zn levels in corn grains in broth crops. Applying 75 t ha^{-1} of sewage sludge, the levels of Zn in the grains were 40.50 and 27.31 mg kg^{-1} in first and second crops, respectively. In regards to this element, a residual effect was found when applying sludge compound on the soil. Even though there was an increase in Zn levels in both crop, being the levels of this mineral in the first crop higher than the second crop, the values stayed below the maximum limit stipulated safe according to Sopper (1993), which claims to be 300 mb kg^{-1}. Oliveira *et al.* (2005), Anjos and Matiazzo (2000), Gomes *et al*. (2006) and Rangel *et al*. (2006), also found an increase in Zn values in corn grains with the increase of sewage sludge dose.

In regards to copper in corn grains (Figure 2), the levels of this mineral was not influenced with the application of sewage sludge, being the average values for the first and second crop 1.95 and 1.13 mg kg^{-1}, respectively. Furthermore, the values were not in the critical toxic level claimed by Sopper (1993). The results were closer to the ones found by Oliveira *et al*. (2005), in which, after 5 years of application of crescent doses of sewage sludge, did not find any anomaly on Cu levels in corn grains. Also, Rangel *et al*. (2006) studied heavy metals in corn grains fertilized for 3 consecutive years with sewage sludge. This experiment noted that during the first year the metals level stayed below the limits. Also, successive sewage sludge application was verified to reduce Cu levels in corn grains by the third year.

In relation to Ni, the increase in sewage sludge doses did not increase the level of this mineral in corn grains. The average values found for Ni were 0.76 and 3.67 mg kg^{-1} in the first and second crops, respectively. Rangel *et al*. (2006) found that the incorporation of 2 different sources of sewage sludge, which are capable to provide 8 times the Ni required for the crop during 3 consecutive years, has low influence on Ni levels in corn grains. This experiment found an increase in levels of this metal only in second crop and the Ni concentration in the sludge was higher from those allowed by CETESB (1999). In addition, Anjos & Matiazzo (2000) found Ni levels at 388 t ha^{-1} to be below the determined limit by the analytical applied method even with high doses of applied residual sludge.

The average levels of Pb (Figure 2) in grains

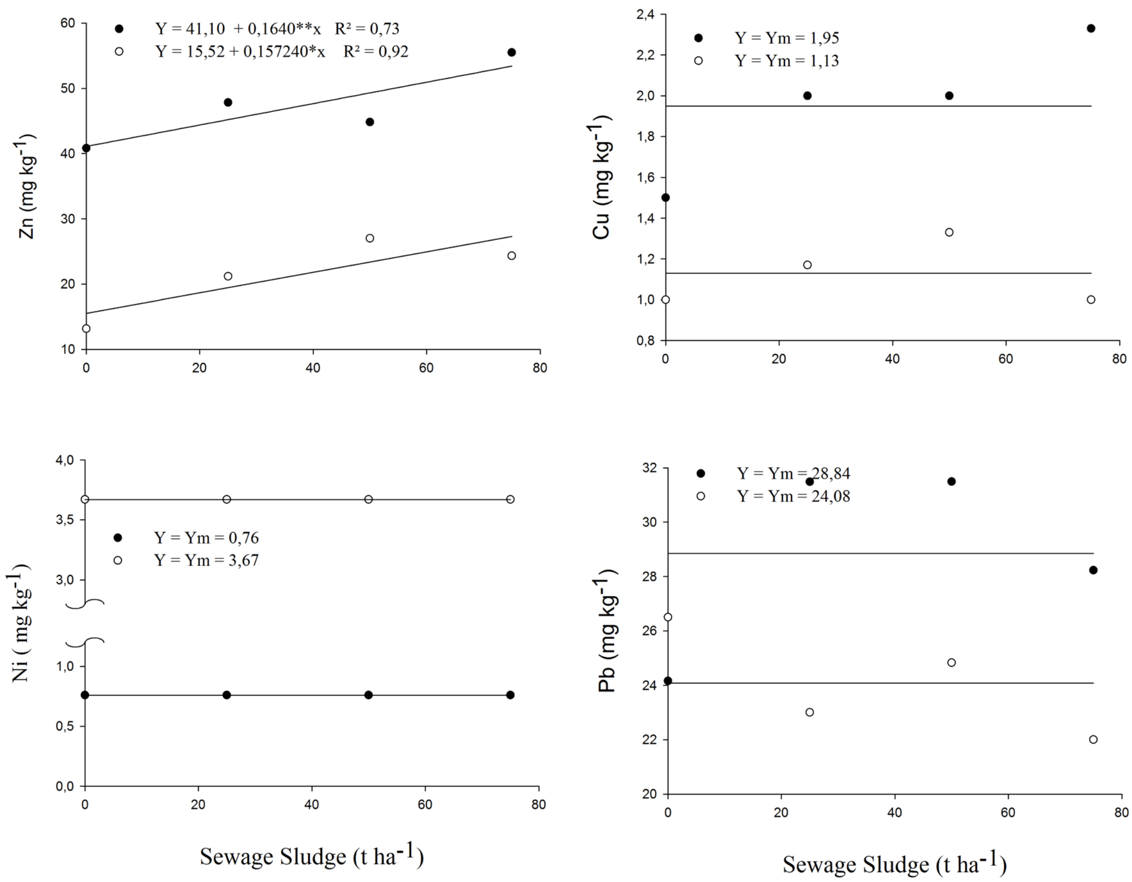

Figure 2. Graphics showing the regression equations linking heavy metals levels in corn seeds with applied doses of sewage sludge

were 22.84 and 24.08 mg kg^{-1} in first and second crops, respectively. These values are higher from those considered safe, 0.2 mg kg^{-1} in dry weight (USEPA 2012). However, the high Pb levels in corn grains are not related to sewage sludge application on the soil, once Pb has not answered to sewage sludge application. Also, treatments that did not receive the compound also reached high Pb levels in the grains. Rangel *et al*. (2006) found that, after three years applying crescent doses of sewage sludge on the soil, Pb levels in corn grains were higher than in the beginning of the experiment. Nonetheless, the levels stayed below the maximum limit established for grains.

As such, only Pb clearly extrapolated the tolerable concentration level for corn grains without being influenced from sewage sludge or rock phosphate application, but rather due to contaminated soil. The lack of sludge influence in metal levels in corn grains has also been reported by Martins et al. (2003), who applied doses up to 80 t ha^{-1} of sewage sludge. Divided in 2, 3, and 4 years or in a unique way, these authors reported that even with high concentrations of heavy metals in the soil due to sewage sludge addition, concentrations of these metals in corn grains were not influenced, being below the maximum allowed limits established by the Health Ministry for chemical contaminants in food (BRASIL, 1998). These authors related higher accumulation of metals in corn leaves, stalks and roots opposing to grains and corncob.

CONCLUSION

- Fertilization with rock phosphate increased the levels of N, P, K and Mg in corn grains only in the first crop. This fertilizer did not influence the levels of Zn, Cu, Ni, Pb, Cr and Cd, on both successive crops.
- Fertilization with sewage sludge compound increased the levels of N, P, K, Mg and Zn in corn grains in the first crop, and P and Zn levels in the second crop. Sewage sludge did not change the levels of Ca, S, Cu, Ni and Pb in any crop.
- Independently of the treatment effect, Pb levels exceeded the recommended limits to use on food.

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