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Residual effect of sewage sludge fertilization on sunflower yield and nutrition

Hermann C. de Albuquerque[1], Geraldo R. Zuba Junio[1], Regynaldo A. Sampaio[1],
Luiz A. Fernandes[2], Fabiano B. S. Prates[2] & Nelson M. B. do Amaral Sobrinho[3]

[1] Instituto de Ciências Agrárias/Universidade Federal de Minas Gerais. Montes Claros, MG. E-mail: agrohermann@yahoo.com.br; juniozuba@yahoo.com.br (Autor correspondente); rsampaio@ufmg.br; larnaldo@ufmg.br
[2] Instituto Federal de Alagoas. Piranhas, AL. Email: fabiano.prates@ifal.edu.br
[3] Departamento de Solos/Instituto de Agronomia/Universidade Federal Rural do Rio de Janeiro. Rio de Janeiro, RJ. E-mail: nelmoura@ufrrj.br

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A B S T R A C T

This study aimed to evaluate the residual effect of sewage sludge fertilization on yield and nutrition of sunflower in its second cycle. The experiment was carried out from April to August 2012. The treatments consisted of four doses of sewage sludge (0, 10, 20 and 30 t ha^{-1}, dry basis) applied in the first cycle of sunflower, distributed in a randomized block design, with six replicates. Sunflower stem diameter, plant height, head diameter and yield increased with the increment in sewage sludge doses, with maximum values observed with the dose of 30 t ha^{-1}. The contents of calcium and magnesium in the soil, pH, sum of bases, effective and potential cation exchange capacity and base saturation increased, while potential acidity and the contents of manganese and iron in the leaves decreased, with the increment in the residual doses of sewage sludge. There was a reduction in yield and growth characteristics of sunflower in the second cycle; thus, additional fertilization with sewage sludge is recommended in every new cycle.

Palavras-chave:
oleaginosas
biossólido
adubação orgânica

Efeito residual da adubação com lodo de esgoto sobre a produção e nutrição de girassol

R E S U M O

Neste trabalho objetivou-se avaliar o efeito residual da adubação com lodo de esgoto sobre a produção e nutrição do girassol em segundo cultivo. O experimento foi realizado no período de abril a agosto de 2012. Os tratamentos corresponderam a quatro doses de lodo de esgoto (0; 10; 20 e 30 t ha^{-1}, em base seca) aplicadas no primeiro cultivo de girassol, distribuídas no delineamento em blocos casualizados, com seis repetições. O diâmetro do caule, a altura da planta, o diâmetro do capítulo e a produtividade do girassol aumentaram com o incremento de lodo de esgoto sendo os valores máximos observados na dose de 30 t ha^{-1}. Os teores de cálcio e magnésio no solo, o pH, a soma de bases, a capacidade de troca catiônica efetiva e potencial e a percentagem de saturação de bases aumentaram enquanto a acidez potencial e os teores de manganês e ferro na folha diminuíram com o incremento das doses residuais de lodo de esgoto. Houve redução na produtividade e nas características de crescimento do girassol no segundo cultivo, recomendando-se novas adubações com lodo, a cada plantio.

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Introduction

The agricultural use of sewage sludge is a viable alternative, since it contains high contents of organic matter and nutrients, and can complement mineral fertilization and reduce production costs (Biondi & Nascimento, 2005; Lemainski & Silva, 2006). In addition, it allows the return of organic residues produced in urban areas to the field, increasing agricultural sustainability (Barbosa et al., 2007). However, it has potential risks of soil and plant contamination with heavy metals, pathogenic microorganisms and organic contaminants (Nascimento et al., 2014; 2015).

The positive effect of sewage sludge in agriculture was confirmed by Nascimento et al. (2011), who observed a good response of papaya plants to the increase in sewage sludge doses. These authors also found agronomic efficiency index of 198% for the application of 60 t ha^{-1} of sewage sludge, compared with chemical fertilization, which evidences the potential of sewage sludge in the improvement of soil physical and chemical characteristics.

Besides the immediate effect of its application, sewage sludge can show residual effect in successive crop cycles and reduce production costs for farmers. Lemainski & Silva (2006) observed that fertilization with 30 t ha^{-1} of sewage sludge caused significant residual effect on maize and a yield corresponding to 77% of that from the first cycle, being 22% more efficient than mineral fertilizer, which points out the importance of using sewage sludge as a residual source of nutrients. Godoi et al. (2008) observed beneficial residual effect of sewage sludge on the chemical, physical and biological components of a degraded soil, which promoted yield increment in the second cut of *Stylosanthes guianensis* cv. 'Mineirão', at 273 days after the first harvest and at 423 days of cultivation.

Based on the above, this study aimed to evaluate the residual effect of sewage sludge fertilization on soil and on sunflower growth, yield and leaf nutrient contents.

Material and Methods

The experiment was carried out from April to August 2012, at the ICA/UFMG, in Montes Claros-MG, Brazil (16° 51' 38" S; 44° 55' 00" W). According to Köppen's classification, the climate of the region is Aw. The soil in the area is a Nitosol, with the following attributes in the layers of 0-20 and 20-40 cm (Table 1).

Table 1. Chemical and physical characteristics of the soil before the first crop cycle

Soil attributes[1]	Layers (cm)			
	0-20	Class[2]	20-40	Class[2]
pH in water	7.00	H	5.40	L
P-Mehlich (mg kg^{-1})	19.10	VG	11.86	M
K (mg dm^{-3})	509.00	VG	96.00	G
Ca (cmol$_c$ dm^{-3})	6.40	VG	3.60	G
Mg (cmol$_c$ dm^{-3})	1.80	VG	1.30	G
Al (cmol$_c$ dm^{-3})	0.00	VL	0.40	L
H + Al (cmol$_c$ dm^{-3})	1.36	L	4.52	M
SB (cmol$_c$ dm^{-3})	9.51	VG	5.15	G
t (cmol$_c$ dm^{-3})	9.51	VG	5.55	G
m (%)	0.00	VL	7.00	VL
T (cmol$_c$ dm^{-3})	10.87	G	9.66	G
V (%)	87.00	VG	53.00	M
Organic matter (dag kg^{-1})	3.39	M	2.00	L
Coarse sand (dag kg^{-1})	6.70	-	4.40	-
Fine sand (dag kg^{-1})	23.30	-	25.60	-
Silt (dag kg^{-1})	26.00	-	16.00	-
Clay (dag kg^{-1})	44.0	-	54.00	-

[1]Analyses according to EMBRAPA (1997); [2]Fertility classes according to Alvarez V. et al. (1999): H – High, VH – Very High, VG – Very Good, G – Good, M – Medium, L – Low, VL – Very Low

The single-cross hybrid 'Hélio 250' of sunflower (*Helianthus annuus* L.) was planted one year after the harvest of the first cycle, in order to evaluate the residual effect of sewage sludge fertilization, at the doses of 0, 10, 20 and 30 t ha^{-1}, on a dry basis. Seeding was performed in the same rows of the first cycle, after incorporating crop residues. The treatments were arranged in a randomized block design, with six replicates.

The sewage sludge used as organic fertilizer was collected in the sewage treatment plant of Montes Claros-MG, administered by the Sanitation Company of Minas Gerais (COPASA-MG). The treatment line consists of a pre-treatment and an upflow anaerobic sludge blanket (UASB) reactor, where the sludge is centrifuged and dewatered using a thermal drier at 350 °C for 30 min.

The sewage sludge doses applied in the first crop cycle were calculated based on the content of available N in the fertilizer (6.0 kg t^{-1}), determined according to the Resolution nº 375 of the National Environmental Council - CONAMA (Brasil, 2006), and on the sunflower N demand for the state of Minas Gerais (60 kg ha^{-1}) (CFSEMG, 1999). The chemical characteristics of the sewage sludge are described in Table 2.

The experimental plots consisted of four 3-m long rows, with spacing of 0.3 m between plants and 0.8 m between rows. The two central rows (20 plants) of each experimental unit were used for the analyses, disregarding 0.5 m on each side, considered as borders.

Furrows were manually opened using a hoe until the depth of 20 cm. Three seeds were planted in each hole and thinning was performed 15 days after emergence, leaving only one plant. At 30 and 60 days after planting, manual weedings were performed for the control of unwanted plants. Sprinkler irrigation, three times a week, was performed during the crop cycle.

At the beginning of the flowering stage, leaf samples were collected from the upper third section of the leaves (Malavolta et

Table 2. Chemical characteristics of the sewage sludge and contents of nutrients applied according to the different doses

Sewage sludge[1] (t ha^{-1})	pH-H$_2$O	Macronutrients (g kg^{-1})								Micronutrients (mg kg^{-1})				
		OC	N$_{total}$	N$_{avail}$	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	B
	6.64	11.62	28.60	6.00	0.77	2.56	2.70	0.27	1.69	531.00	42.034.50	218.0	135.50	10.90
	Contents applied (kg ha^{-1})													
10	-	-	286.0	60.0	7.7	25.6	27.0	2.7	16.9	5.31	420.35	2.18	1.36	0.11
20	-	-	572.0	120.0	15.4	51.2	54.0	5.4	33.8	10.62	840.69	4.36	2.72	0.22
30	-	-	858.0	180.0	23.1	76.8	81.0	8.1	50.7	15.93	1.261.04	6.54	4.08	0.33

OC - Organic carbon (g kg^{-1}); N$_{avail}$ – Content of available nitrogen, calculated according to Brasil (2006); [1]Analysis according to Tedesco et al. (1995)

al., 1997) of 12 plants in the experimental plot, for the analyses of N, P, K, Ca, Mg, S, Zn, Cu, Mn, Fe and B (Tedesco et al., 1995).

At the end of the experiment, in the harvesting stage (R9), when the capitula were facing down, the following variables were evaluated: stem diameter, using a digital caliper near the soil surface; plant height, using a steel tape measure from the soil surface to the apex of the plant; and head diameter, determined with a tape measure. In addition, grain yield was estimated using the weight of grains corrected to 12% of humidity, considering all the grains collected in each plant.

After harvesting, 8 subsamples of soil were collected in each experimental plot from the layers of 0-20 and 20-40 cm, in order to form composite samples for the analyses of organic matter, pH, P, K, Ca, Mg, S, H+Al, Al, Zn, Cu, Mn and Fe (EMBRAPA, 1997), and B (Tedesco et al., 1995). Then, sum of bases (SB), effective cation exchange capacity ($CEC_{(t)}$), potential cation exchange capacity ($CEC_{(T)}$) and the percentage of base saturation (V%) (EMBRAPA, 1997) were calculated.

The data were subjected to the analysis of variance and the sewage sludge doses were fitted to regression models, testing the coefficients until 0.1 probability level by t-test. For the comparison between variables from the first and second cycle, the confidence intervals of the means were calculated, considering a 0.05 probability level by t-test.

Results and Discussion

Residual effect of sewage sludge fertilization was observed on sunflower yield (Table 3), which reached a maximum value of 1,073.47 kg ha^{-1} for the dose of 30 t ha^{-1} of sewage sludge, which corresponds to 72% of the mean yield in Brazil estimated for the 2011/2012 crop season, under irrigated and rainfed conditions, according to CONAB (2012). These results corroborate those observed by Barbosa et al. (2007) and Zuba Junio et al. (2012), who observed a positive response in maize yield to the residual effect of sewage sludge application in the soil. According to Nascimento et al. (2014), the increase in the yield of crops fertilized with sewage sludge is due to the improvement in soil chemical, physical and biological quality.

Stem diameter, plant height and head diameter increased with the increments in the residual doses of sewage sludge, for the application of up to 30 t ha^{-1} (Table 3). In addition, the positive and statistically significant correlation between capitulum growth and grain yield (r = 0.94**) must be pointed out. Plant height results corroborate those obtained by Costa et al. (2009), who observed residual effect of sewage sludge on the height of maize plants for the application of 75 and 150 kg ha^{-1}. On the other hand, these authors did not observe significant increments in stem diameter, despite using sewage sludge doses higher than those tested in this study.

P availability values in the evaluated soil layers were classified as very good and medium (Alvarez V. et al., 1999), and were not influenced by the residual effect of the sewage sludge fertilization (Table 4). Although the sewage sludge has supplied P (Table 1), the amounts were only enough for the first crop cycle. These results differ from those observed by Barbosa

Table 3. Regression equations between yield (Y), stem diameter (SD), plant height (PH) and head diameter (HD) of sunflower and the doses of sewage sludge

Variable	Equation	R^2	SSD (t ha^{-1})	MV	MY
Y (kg ha^{-1})	$Y = 853.05 + 0.244908^{***}X^2$	0.9153	30.00	1,073.47	1.494,00
SD (mm)	$Y = 18.06 + 0.413820^{***}X$	0.9938	30.00	30.48	-
PH (m)	$Y = 1.42 + 0.055588^{***}X^{0.5}$	0.9672	30.00	1.73	-
HD (cm)	$Y = 13.40 + 0.006864^{***}X^2$	0.9729	30.00	19.58	-

SSD - Sewage sludge dose causing the maximum value of the variable; MV - Maximum value of the variable within the experimental interval; MY - Mean yield of sunflower in Brazil (irrigated and rainfed), predicted for the 2011/2012 crop season, in kg ha^{-1}; ***Significant at 0.01 probability level by t-test

Table 4. Regression equations between soil nutrient contents and the residual doses of sewage sludge

Nutrient	Layer	Equation	R^2	SSD (t ha^{-1})	MCS	CMY	Class[1]
P (mg dm^{-3})	(0-20 cm)	Y = Ym = 19.1	-	-	19.10	19.10	VG
	(20-40 cm)	Y = Ym = 9.91	-	-	9.91	9.91	M
K (mg dm^{-3})	(0-20 cm)	Y = Ym = 103.0	-	-	103.0	103.00	G
	(20-40 cm)	Y = Ym = 89.54	-	-	89.54	89.54	G
Ca (cmol$_c$ dm^{-3})	(0-20 cm)	Y = Ym = 8.07	-	-	8.07	8.07	VG
	(20-40 cm)	$Y = 5.83 + 0.208232^{\circ}X^{0.5}$	0.9591	30.00	6.97	6.97	VG
Mg (cmol$_c$ dm^{-3})	(0-20 cm)	Y = Ym = 1.28	-	-	1.28	1.28	G
	(20-40 cm)	$Y = 1.11 + 0.029982^{*}X^{0.5}$	0.9098	30.00	1.27	1.27	G
S (mg dm^{-3})	(0-20 cm)	Y = Ym = 14.75	-	-	14.75	14.75	VG
	(20-40 cm)	Y = Ym = 25.2	-	-	25.20	25.20	VG
Cu (mg dm^{-3})	(0-20 cm)	Y = Ym = 0.98	-	-	0.98	0.98	M
	(20-40 cm)	Y = Ym = 0.84	-	-	0.84	0.84	M
Zn (mg dm^{-3})	(0-20 cm)	Y = Ym = 3.0	-	-	3.00	3.00	H
	(20-40 cm)	Y = Ym = 1.8	-	-	1.80	1.80	G
Mn (mg dm^{-3})	(0-20 cm)	Y = Ym = 15.5	-	-	15.50	15.50	H
	(20-40 cm)	Y = Ym = 8.4	-	-	8.40	8.40	M
Fe (mg dm^{-3})	(0-20 cm)	Y = Ym = 68.7	-	-	68.70	68.70	H
	(20-40 cm)	Y = Ym = 55.5	-	-	55.50	55.50	H
B (mg dm^{-3})	(0-20 cm)	Y = Ym = 0.20	-	-	0.20	0.20	L
	(20-40 cm)	Y = Ym = 0.10	-	-	0.10	0.10	VL

SSD – Sewage sludge dose causing the highest content of the nutrient in the soil; MCS – Maximum content of the nutrient in the soil; CMY – Content in the soil for the sewage sludge dose causing maximum yield; Ym – mean value; [1] Fertility classes according to Alvarez V. et al. (1999): H – High, VG – Very Good, G – Good, M – Medium, L – Low, VL – Very Low; °, *Significant at 0.1 and 0.05 probability level by t-test et al. (2007), who reported increments in soil P contents caused by the residual effect of sewage sludge application.

There was no residual effect of sewage sludge fertilization on K contents in the soil (Table 4), which were classified as good according to Alvarez V. et al. (1999). Similar results were reported by Barbosa et al. (2007), who did not observe residual effect of sewage sludge application on K contents in the soil.

Ca contents in the layer of 0-20 cm were not influenced by the residual effect of sewage sludge fertilization. However, this effect was significant for the layer of 20-40 cm, and the highest value was obtained for the maximum dose of sewage sludge, 30 t ha^{-1} (Table 4). This can be related to the movement of Ca supplied by the highest sewage sludge doses to the layer of 20-40 cm. Nevertheless, Ca contents in the studied layers were classified as very good (Alvarez V. et al., 1999). Zuba Junio et al. (2012), studying maize, observed residual effect of the application of increasing doses of a sewage sludge compound in all the studied soil layers, until the dose of approximately 39 t ha^{-1}.

As observed for Ca, Mg contents in the soil were influenced by the residual effect of sewage sludge doses in the layer of 20-40 cm, with the highest value observed for the dose of 30 t ha^{-1} (Table 4), which did not occur for the layer of 0-20 cm. As observed for Ca, part of the Mg applied with the highest sewage sludge doses moved to the layer of 20-40 cm. Increase in the Mg contents in the soil as a function of the residual effect of sewage sludge fertilization was also observed by Barbosa et al. (2007). The available contents of this nutrient were classified as good in the present study (Alvarez V. et al., 1999).

There was no residual effect of the sewage sludge doses on S contents (Table 4), which were classified as very good in both evaluated layers, according to Alvarez V. et al. (1999).

The contents of micronutrients were not influenced by the residual effects of the sewage sludge doses applied in the first crop cycle (Table 4). These results differ from those reported by Oliveira et al. (2005), who observed residual effect for Zn, which tended to remain in the layer of 0-20 cm. Sukkariyah et al. (2005) observed that, after 17 years of cultivation, more than 75% of Zn and 85% of Cu applied through sewage sludge fertilization remained in the layer of incorporation, which is not desirable, because of the possibility of reaching phytotoxic levels. Among the micronutrients evaluated in this study, only B showed contents classified as low and very low (Alvarez V. et al., 1999) in the layers of 0-20 and 20-40 cm, respectively (Table 4). This fact can be explained by the low B content supplied to the soil through the sewage sludge fertilization in the first crop cycle (Table 2), which corresponded to 1/3 of the amount recommended for sunflower cultivation.

There was no residual effect of sewage sludge application, in any of the evaluated layers, on the organic matter contents, which were classified as medium, according to Alvarez V. et al. (1999) (Table 5). Antolin et al. (2005) observed that, one year after sewage sludge application, the organic matter contents were similar in fertilized and non-fertilized plots, because of a rapid mineralization of the organic matter, which is corroborated by the results of the present study. However, Barbosa et al. (2007) reported residual increase of soil organic matter with the application of sewage sludge.

For soil pH (Table 5), there was residual effect of sewage sludge fertilization in the layer of 20-40 cm, with values classified as very high (Alvarez V. et al., 1999), corresponding to 7.3 at the dose of 30 t ha^{-1}. These results confirm those obtained by Barbosa et al. (2007), who found that the residual effect of the application of increasing doses of sewage sludge promoted increase in soil pH. On the other hand, Antolin et al. (2005) and Caldeira Júnior et al. (2009) observed that doses of up to 30 t ha^{-1} caused a reduction in this variable, which can be associated with the production of organic acids during the degradation of the residues by the microorganisms. The increase in soil pH, due to the application of sewage sludge, observed in some studies, can be due to the alkalinity of the materials used in processes of pathogen elimination and sludge stabilization (Nascimento et al., 2004). In this study, it should be taken into consideration that pH values classified as very high in both evaluated layers can be related to the use of calcareous water in the irrigation, which shows the following characteristics: pH = 7.6; electrical conductivity = 468 us cm^{-1} and total hardness and $CaCO_3$ = 222 mg L^{-1}.

The residual effect of sewage sludge application was observed for SB, $CEC_{(t)}$ and $CEC_{(T)}$ only in the layer of 20-40 cm, which showed levels classified from good to very good

Table 5. Regression equations relating chemical attributes and fertility indices with the residual effect of sewage sludge doses applied to the soil

Variable	Layer	Equation	R^2	SSD (t ha^{-1})	MCS	CMY	Class[1]
OM (%)	(0-20 cm)	$Y = Ym = 2.6$	-	-	2.6	2.6	M
	(20-40 cm)	$Y = Ym = 2.2$	-	-	2.2	2.2	M
pH	(0-20 cm)	$Y = Ym = 7.7$	-	-	7.7	7.7	VH
	(20-40 cm)	$Y = 6.69 + 0.02016^{\circ}X$	0.9120	30.00	7.3	7.3	VH
SB ($cmol_c\ dm^{-3}$)	(0-20 cm)	$Y = Ym = 9.8$	-	-	9.8	9.8	VG
	(20-40 cm)	$Y = 7.48 + 0.04335^{*}X$	0.8308	30.00	8.7	8.7	VG
$CEC_{(t)}$ ($cmol_c\ dm^{-3}$)	(0-20 cm)	$Y = Ym = 9.8$	-	-	9.8	9.8	VG
	(20-40 cm)	$Y = 7.59 + 0.03885^{\circ}X$	0.8529	30.00	8.7	8.7	VG
$CEC_{(T)}$ ($cmol_c\ dm^{-3}$)	(0-20 cm)	$Y = Ym = 9.9$	-	-	9.9	9.9	G
	(20-40 cm)	$Y = 8.73 + 0.098234^{*}X^{0.5}$	0.9040	30.00	9.3	9.3	G
V %	(0-20 cm)	$Y = 98.04 + 0.981735^{*}X^{0.5} - 0.150834^{\circ}X$	0.7340	10.59	99.6	98.9	VG
	(20-40 cm)	$Y = 84.59 + 0.32668^{\circ}X$	0.8307	30.00	94.4	94.4	VG
Al^{3+} ($cmol_c\ dm^{-3}$)	(0-20 cm)	$Y = Ym = 0.00$	-	-	0.00	0.00	VL
	(20-40 cm)	$Y = Ym = 0.04$	-	-	0.04	0.04	VL
H+Al ($cmol_c\ dm^{-3}$)	(0-20 cm)	$Y = 0.18 - 0.095826^{*}X^{0.5} + 0.014821^{\circ}X$	0.7433	0.00	0.18	0.10	VL
	(20-40 cm)	$Y = 1.42 - 0.154044^{\circ}X^{0.5}$	0.9756	0.00	1.42	0.58	VL

SSD – Sewage sludge dose causing the highest value of the variable in the soil; MCS – Maximum content in the soil; CMY – Content in the soil for the sewage sludge dose causing maximum yield; Ym – Mean value; [1] Fertility classes according to Alvarez V. et al. (1999): H – High, VH – Very High, VG – Very Good, G – Good, M – Medium, L – Low, VL – Very Low; °, *Significant at 0.01 and 0.05 probability level by t-test

(Alvarez V. et al., 1999) in both evaluated layers (Table 5). According to Barbosa et al. (2007), sewage sludge increases in soil negative charges, due to its high content of organic matter, besides enriching the medium with Ca and Mg, which contributes to the increase of soil CEC.

The treatments with sewage sludge showed residual effect on V% values in the layers of 0-20 and 20-40 cm (Table 5), which are classified as very good with respect to fertility (Alvarez V. et al., 1999). These results in the layer of 0-20 cm corroborate those obtained by Barbosa et al. (2007), who observed an increase in base saturation in the layer of 0-20 cm caused by the residual effect of sewage sludge application, due to the supply of Ca and Mg by the organic matter.

H+Al values were influenced by the residual effect of sewage sludge in the layers of 0-20 and 20-40 cm (Table 5), but were classified as very low, according to Alvarez V. et al. (1999). For Al, no residual effect was observed in any of the evaluated layers.

The contents of macronutrients in sunflower leaves were not influenced by the residual effect of sewage sludge applied in the first cycle; Mg and S remained below the nutrient sufficiency range in the plant (Table 6) (Albuquerque et al., 2015). According to Zuba Junio et al. (2012), the residual effects of sewage sludge fertilization influence the leaf contents of N, P and K, after one year of its application in the soil and two consecutive maize cycles. Still according to these authors, the contents of Mg and S remain below the amounts demanded by maize, which confirms the results obtained in this experiment and indicates the need for additional sewage sludge fertilization in each new cycle of sunflower.

The contents of micronutrients in sunflower leaves (Table 6) were not influenced by the residual effect of sewage sludge application, except for Mn and Fe. The contents of these elements decreased as the doses increased, which was possibly associated with the increase in pH in the layer of 20-40 cm (Table 5). In addition, micronutrient contents remained within the nutrient sufficiency range for sunflower. These results differ from those reported by Zuba Junio et al. (2011), who observed increase in Zn contents of maize plants with the increment in the residual fertilization with sewage sludge of up to 63.62 t ha^{-1}, an effect also observed for other doses by Gomes et al. (2007). In addition, Zuba Junio et al. (2011) did not observe effect of sewage sludge treatments on the contents of Cu in the plant, which corroborates the results obtained in this study.

Sunflower yield in the second cycle corresponded to 71% of the yield in the first cycle and the biometric characteristics also decreased (Table 7). These results for grain yield are similar

Table 7. Confidence interval of the means for yield, biometric characteristics, chemical attributes, fertility indices and soil nutrient contents in two consecutive cycles of sunflower

Variable	1° cycle[1]		2° cycle[2]	
	Mean	CI'	Mean	CI'
YIELD (kg ha^{-1})	1,321.31	±36.12	938.51	±21.12
SD (mm)	27.54	±1.05	24.32	±0.84
PH (m)	1.79	±0.04	1.61	±0.02
HD (cm)	17.51	±0.91	15.82	±0.72
OM % (0-20 cm)	3.18	±0.39	2.62	±0.21
OM % (20-40 cm)	2.12	±0.21	2.21	±0.32
pH (0-20 cm)	6.91	±0.25	7.71	±0.15
pH (20-40 cm)	6.72	±0.29	6.92	±0.41
SB (cmolc dm^{-3}) (0-20 cm)	9.81	±0.92	9.81	±0.42
SB (cmolc dm^{-3}) (20-40 cm)	6.63	±1.16	8.11	±0.82
$CEC_{(t)}$ (cmolc dm^{-3}) (0-20 cm)	9.82	±0.89	9.82	±0.41
$CEC_{(t)}$ (cmolc dm^{-3}) (20-40 cm)	6.61	±1.11	8.21	±0.83
$CEC_{(T)}$ (cmolc dm^{-3}) (0-20 cm)	10.72	±0.88	9.92	±0.41
$CEC_{(T)}$ (cmolc dm^{-3}) (20-40 cm)	8.62	±0.73	9.05	±0.41
V % (0-20 cm)	91.45	±3.52	99.00	±0.92
V % (20-40 cm)	75.83	±8.83	86.51	±10.32
Al (cmolc dm^{-3}) (20-40 cm)	0.03	±0.06	0.04	±0.07
H + Al (cmolc dm^{-3}) (0-20 cm)	0.92	±0.31	0.09	±0.09
H + Al (cmolc dm^{-3}) (20-40 cm)	2.12	±0.62	0.92	±0.51
P (mg dm^{-3}) (0-20 cm)	29.03	±17.68	19.13	±7.08
P (mg dm^{-3}) (20-40 cm)	16.92	±17.29	9.91	±7.42
K (mg dm^{-3}) (0-20 cm)	142.25	±56.59	103.00	±21.73
K (mg dm^{-3}) (20-40 cm)	93.25	±42.56	89.54	±35.62
Ca ($cmol_c$ dm^{-3}) (0-20 cm)	7.88	±0.71	8.07	±0.36
Ca ($cmol_c$ dm^{-3}) (20-40 cm)	5.32	±1.34	6.52	±0.73
Mg ($cmol_c$ dm^{-3}) (0-20 cm)	1.47	±0.18	1.28	±0.07
Mg ($cmol_c$ dm^{-3}) (20-40 cm)	1.21	±0.14	1.21	±0.12
S (mg dm^{-3}) (0-20 cm)	32.92	±12.64	14.75	±3.03
S (mg dm^{-3}) (20-40 cm)	36.47	±10.43	25.21	±7.64
Cu (mg dm^{-3}) (0-20 cm)	0.98	±0.24	0.98	±0.23
Cu (mg dm^{-3}) (20-40 cm)	0.76	±0.27	0.84	±0.22
Zn (mg dm^{-3}) (0-20 cm)	4.77	±3.09	3.01	±1.32
Zn (mg dm^{-3}) (20-40 cm)	1.76	±1.83	1.82	±1.31
Mn (mg dm^{-3}) (0-20 cm)	16.36	±3.27	15.53	±2.72
Mn (mg dm^{-3}) (20-40 cm)	5.77	±2.92	8.42	±3.52
Fe (mg dm^{-3}) (0-20 cm)	75.62	±17.61	68.72	±21.02
Fe (mg dm^{-3}) (20-40 cm)	60.64	±11.72	55.53	±20.12
B (mg dm^{-3}) (0-20 cm)	0.22	±0.08	0.20	±0.05
B (mg dm^{-3}) (20-40 cm)	0.11	±0.04	0.10	±0.05

Confidence interval of the mean at 0.05 probability level by t-test; SD – Stem diameter; PH – Plant height; HD – Head diameter; OM – Organic matter; SB – Sum of bases; $CEC_{(t)}$ – effective cation exchange capacity; $CEC_{(T)}$ – potential cation exchange capacity; V% - Base saturation; Al was not detected in the layer of 0-20 cm; Crop cycle: 120 days; [1]Planted in April 2011; [2]Planted in April 2012

Table 6. Regression equations between the nutrient contents in sunflower leaves and the residual doses of sewage sludge

Nutrient	Equation	R^2	SSD (t ha^{-1})	MCP	CMY	SR[1]	SR[2]
N (dag kg^{-1})	Y = Ym = 4.24	-	-	4.24	4.24	3.3-3.5	-
P (dag kg^{-1})	Y = Ym = 0.40	-	-	0.40	0.40	0.4-0.7	-
K (dag kg^{-1})	Y = Ym = 3.20	-	-	3.20	3.20	2.0-2.4	-
Ca (dag kg^{-1})	Y = Ym = 2.81	-	-	2.81	2.81	1.7-2.2	-
Mg (dag kg^{-1})	Y = Ym = 0.36	-	-	0.36	0.36	0.9-1.1	-
S (dag kg^{-1})	Y = Ym = 0.30	-	-	0.30	0.30	0.5-0.7	-
Zn (mg kg-1)	Y = Ym = 72.25	-	-	72.25	72.25	-	30 - 80
Cu (mg kg-1)	Y = Ym = 33.50	-	-	33.50	33.50	-	25 - 100
Mn (mg kg-1)	$Y = 53.81 – 6.828164^{*}X^{0.5} + 1.129781^{\circ}X$	0.9977	0.00	53.81	50.30	-	10 - 20
Fe (mg kg-1)	$Y = 418.07 – 34.477339^{*}X^{0.5} + 5.881819^{\circ}X$	0.9989	0.00	418.07	405.68	-	80 - 120
B (mg kg-1)	Y = Ym = 35.70	-	-	35.70	35.70	-	35 - 100

SSD – Sewage sludge dose causing the highest content of the nutrient in the plant; MCP – Maximum content of the nutrient in the plant; CMY – Content in the plant for the sewage sludge dose causing maximum yield; [1]Nutrient sufficiency range in the plant, according to Malavolta et al. (1997); [2]Nutrient sufficiency range, according to Oliveira (2004); °,*Significant at 0.01 and 0.05 probability level by t-test to those reported by Lemainski & Silva (2006), who observed that the application of sewage sludge doses of 30 and 45 t ha^{-1} promoted yields corresponding to 77 and 80% of those from the first cycle, respectively. In the present study, the reduction in yield and biometric characteristics can be related to the contents of organic matter and S in the soil, which decreased from the first to the second cycle, besides the low contents of B in both cycles. Despite the reduction, the contents of soil organic matter were classified as medium (Alvarez V. et al., 1999). Although there was no statistical difference between the means of P and K from the first to the second cycle, the reduction contributed to a change in the agronomic classification (Alvarez V. et al., 1999) in the layer of 20-40 cm for P, from good to medium, and in the layer of 0-20 cm for K, from very good to good. Thus, additional fertilization with sewage sludge is recommended in each cycle.

As shown in Table 8, the contents of macronutrients in the leaves remained within the sufficiency range for this crop (Malavolta et al., 1997), except for Mg and S, which could be a limitation for plant growth and development. It should be pointed out that the contents of K were higher in the second cycle in comparison to the first one.

With respect to the micronutrients in plant leaves, there was an increase in the contents of Cu and Zn in the second cycle (Table 8). Cu content was within the adequate nutritional range for this crop (Oliveira et al., 2009), which was not observed in the first cycle. Fe leaf contents were lower in the second cycle (Table 8), which can be attributed to the insolubilization of this element at pH close to alkalinity and to the complexing power of the organic matter, which reduces the availability of P for plants (Cunha et al., 2011). B leaf contents were also reduced compared with the first cycle, which can be related to its low concentration in the sewage sludge applied to the soil.

Table 8. Confidence intervals of the means for nutrient contents in sunflower leaves, in two consecutive cycles

Variable	1° cycle[1]		2° cycle[2]	
	Mean	CI'	Mean	CI'
N-leaf (dag kg^{-1})	4.54	±0.33	4.24	±0.44
P-leaf (dag kg^{-1})	0.57	±0.11	0.41	±0.05
K-leaf (dag kg^{-1})	2.52	±0.27	3.21	±0.13
Ca-leaf (dag kg^{-1})	3.17	±0.2	2.81	±0.24
Mg-leaf (dag kg^{-1})	0.42	±0.03	0.36	±0.04
S-leaf (dag kg^{-1})	0.33	±0.05	0.31	±0.04
Zn-leaf (mg kg^{-1})	44.12	±3.71	72.25	±13.3
Cu-leaf (mg kg^{-1})	17.82	±1.89	33.5	±10.12
Mn-leaf (mg kg^{-1})	38.00	±6.05	48.41	±7.02
Fe-leaf (mg kg^{-1})	558.00	±76.71	393.32	±31.95
B-leaf (mg kg^{-1})	51.40	±6.51	35.73	±4.81

Confidence interval of the man at 0.05 probability level by t-test; Crop cycle: 120 days; [1]Planted in April 2011; [2]Planted in April 2012

Conclusions

1. Sewage sludge doses of up to 30 t ha^{-1} increased growth and yield of sunflower plants in the second cycle; however, the response is lower compared with the first cycle and additional fertilization with sewage sludge is recommended in each new cycle.

2. The contents of organic matter and nutrients in the soil, except calcium and magnesium, and contents of nutrients in the leaves, except manganese and iron, were not influenced by the residual effect of the fertilization with sewage sludge.

3. The contents of calcium and magnesium in the soil, pH, sum of bases, effective and potential cation exchange capacity and base saturation percentage increased, while effective acidity decreased, with the increment in the residual doses of sewage sludge.

4. The contents of manganese and iron in leaf tissues decreased with the increment in the residual doses of sewage sludge.

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