ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.19, n.6, p.553–559, 2015
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v19n6p553-559

Yield and nutrition of sunflower fertilized with sewage sludge

Hermann C. de Albuquerque[1], Geraldo R. Zuba Junio[1], Regynaldo A. Sampaio[1], Luiz A. Fernandes[1], Everaldo Zonta[2] & Cristiane F. Barbosa[1]

[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; crisfbsp@gmail.com
[2] Departamento de Solos/ Universidade Federal Rural do Rio de Janeiro. Seropédica, RJ. E-mail: ezonta@ufrrj.br

Key words:
Helianthus annuus L.
biosolid
organic fertilization
soil pollution

ABSTRACT
The aim of this study was to evaluate the effect of thermally dried sewage sludge on soil fertility, growth and yield of sunflower. The experiment was conducted in a Nitosol area of the Institute of Agricultural Sciences of the Federal University of Minas Gerais, in Montes Claros-MG, Brazil. The treatments consisted of four doses of sewage sludge (0, 10, 20 or 30 t ha^{-1}, dry weight basis), with six replicates in a randomized block design. The levels of nutrients in soil and plant, soil fertility indices, stem diameter, plant height, head diameter and grain yield were evaluated. Stem diameter, plant height, head diameter and grain yield increased with increasing doses of sewage sludge. The application of the residue increased linearly the contents of soil organic matter and N in sunflower leaves. On the other hand, pH, the exchangeable bases, total and effective cation exchange capacity, base saturation, H+Al, Al, soil contents of P, K, Ca, Mg, S, Zn, Cu, Mn, Fe and B, and the leaf contents of P, K, Ca, Mg, S, Zn, Cu, Mn, Fe and B were not influenced by the application of sewage sludge doses of up to 30 t ha^{-1}.

Palavras-chave:
Helianthus annuus L.
biossólido
adubação orgânica
poluição do solo

Produção e nutrição de girassol adubado com lodo de esgoto

RESUMO
Objetivou-se, neste trabalho, avaliar o efeito da aplicação de lodo de esgoto termicamente seco sobre a fertilidade do solo, o crescimento e a produtividade do girassol. O experimento foi realizado em área de Nitossolo do Instituto de Ciências Agrárias da Universidade Federal de Minas Gerais, em Montes Claros, MG. Os tratamentos corresponderam a quatro doses de lodo de esgoto (0, 10, 20 e 30 t ha^{-1}, em base seca), com seis repetições, no delineamento em blocos casualizados. Foram avaliados os teores de nutrientes no solo e na planta, os índices de fertilidade do solo, o diâmetro do caule, a altura da planta, o diâmetro do capítulo e a produtividade de grãos. O diâmetro do caule, altura da planta, diâmetro do capítulo e a produtividade do girassol aumentaram com o incremento das doses de lodo de esgoto. A aplicação do resíduo proporcionou aumento linear no teor de matéria orgânica do solo e no teor de N nas folhas de girassol. O pH, a soma de bases, a capacidade de troca catiônica total e efetiva, a percentagem de saturação de bases, o H+Al, o Al e os teores de P, K, Ca, Mg, S, Zn, Cu, Mn, Fe e B no solo e de P, K, Ca, Mg, S, Zn, Cu, Mn, Fe e B na folha de girassol não foram influenciados pela aplicação de doses de lodo de esgoto de até 30 t ha^{-1}.

Protocolo 143-2014 – 07/05/2014 • Aprovado em 19/12/2014 • Publicado em 04/05/2015

Introduction

Sewage treatment has caused sludge accumulation in treatment stations and problems in its destination, since the disposal of organic matter in landfills or its incineration also cause large damages to the environment (Pedroza et al., 2003). In this context, there is the need to look for sustainable solutions for the final disposal of this residue, and its agricultural use is considered as an excellent alternative from the environmental perspective (Barbosa et al., 2007).

According to Lemainski & Silva (2006), sewage sludge represents a good source of organic matter to the soil and of essential elements to plants, and it can complement mineral fertilizers and reduce production costs. However, caution should be taken in its use, due to probable contaminations with pathogens, heavy metals and persistent organic substances, besides the possibility of nitrate loss through leaching and contamination of ground waters.

Many authors report that increments in sludge doses have caused increases in sunflower yield (Ribeirinho et al., 2012; Lobo et al., 2013); however, other crops have also shown good yields, like castor bean (Nascimento et al., 2011), maize and bean (Nascimento et al., 2004). These positive effects are attributed to the supply of nutrients, especially nitrogen, by the residue and to the beneficial effects on physical attributes of soil (Caldeira Júnior et al., 2009; Nascimento et al., 2014).

The high costs of chemical fertilizers, due to the high energy demand in their industrialization, increase the costs of cropped areas, besides being counterintuitive when used in the production of crops for biofuels. Thus, because it is rich in nutrients, sewage sludge becomes a viable alternative in the fertilization of oilseed crops, which can be used as either a substitute or a complement of nitrogen fertilization (Ribeirinho et al., 2012).

This study aimed to evaluate the effect of the application of thermally dried sewage sludge on soil fertility and sunflower growth and yield.

Material and Methods

The experiment was carried out from April to August 2011, in a Nitosol area of the Institute of Agricultural Sciences of the Federal University of Minas Gerais, (ICA/UFMG), in Montes Claros-MG, Brazil. Chemical and physical characteristics of the soil layers of 0-0.20 and 0.20-0.40 m are shown in Table 1.

The single-cross hybrid 250 of sunflower (*Helianthus annuus* L.) was used in the experiment. Treatments corresponded to 4 doses of sewage sludge (0, 10, 20 and 30 t ha^{-1}, dry weight basis), with six replicates, in a randomized block design.

Table 1. Chemical and physical characteristics of the soil used in the experiment

Soil attribute[1]	Layers (m)			
	0-0.20	Class[2]	0.20-0.40	Class[2]
pH in water	7.00	High	5.40	Low
P-Mehlich (mg kg^{-1})	19.10	Very good	11.86	Medium
K (mg dm^{-3})	509.00	Very good	96.00	Good
Ca (cmol$_c$ dm^{-3})	6.40	Very good	3.60	Good
Mg (cmol$_c$ dm^{-3})	1.80	Very good	1.30	Good
Al (cmol$_c$ dm^{-3})	0.00	Very low	0.40	Low
H + Al (cmol$_c$ dm^{-3})	1.36	Low	4.52	Medium
SB (cmol$_c$ dm^{-3})	9.51	Very good	5.15	Good
t (cmol$_c$ dm^{-3})	9.51	Very good	5.55	Good
m (%)	0.00	Very low	7.00	Very low
T (cmol$_c$ dm^{-3})	10.87	Good	9.66	Good
V (%)	87.00	Very good	53.00	Medium
Organic matter (dag kg^{-1})	3.39	Medium	2.00	Low
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})	44.00	-	54.00	-

[1] Analysis according to methodologies recommended by EMBRAPA (1997);
[2] Fertility classes according to Alvarez V. et al. (1999)

Dewatered sewage sludge was collected in the Sewage Treatment Plant - STP of Montes Claros-MG, administered by the Sanitation Company of Minas Gerais - COPASA. The treatment line consists of a pretreatment and an upflow anaerobic sludge blanket (UASB) reactor. The sludge generated in the UASB reactor was centrifuged and dewatered in a thermal drier at 350 °C, for 30 min.

Sewage sludge doses were based on the content of available nitrogen (6.0 kg t^{-1}), calculated as described in the Resolution No. 375 of the National Environmental Council - CONAMA (Brasil, 2006) and on the recommendation to meet crop demand (60 kg ha^{-1}), indicated by the Minas Gerais Soil Fertility Commission (CFSEMG, 1999). Characteristics of sewage sludge chemical characteristics are presented in Table 2.

The experimental plots constituted of four 3.0 m long rows, with spacing of 0.3 m between plants and 0.8 m between rows. The useful area of each experimental plot consisted of the two central rows (20 plants), disregarding 0.5 m on each side, considered as borders.

For the soil tillage, the area was harrowed and then the furrows were opened at depth of 0.20 m. The fertilization with sewage sludge was performed all at once in the planting furrows, according to the established treatments, and the residue was incorporated with the aid of a hoe. Three sunflower seeds were manually planted 0.30 m apart in the row and thinning was performed 15 days after emergence, leaving only one plant; manual weeding was performed at 30 and 60 days after planting, to control unwanted plants, and sprinkler irrigation was used during the entire crop cycle.

Table 2. Sewage sludge chemical characteristics and the amounts of nutrients applied with the different doses

Sewage sludge dose (t ha^{-1})	Macronutrients (g kg^{-1})									Micronutrients (mg kg^{-1})				
	pH_{H2O}	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
	Applied amounts (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

Analysis according to: Tedesco et al. (1995) and Abreu et al. (2006); OC - Organic carbon (g kg^{-1}); N_{avail} - Content of available nitrogen calculated according to the CONAMA Resolution nº 375 (Brasil, 2006)

At the beginning of the flowering stage, leaf samples were collected from the upper third part of 12 plants, randomly chosen in the observation area of each plot, for analysis of N, P, K, Ca, Mg, S, Zn, Cu, Mn, Fe and B (Tedesco et al., 1995; Malavolta et al., 1997; Oliveira, 2004).

At the end of the experiment, in the harvesting phase (R9), when capitula were facing down, the following parameters were evaluated in the observation area of each plot: stem diameter, plant height, head diameter and grain yield. Stem diameter was measured close to the soil surface using a digital caliper rule; plant height was measured with a steel tape measure, from soil surface to the apex of the plant, the head diameter was measured using a tape measure and grain yield was estimated using the weight of grains determined with a precision scale.

After harvesting, 8 subsamples of soil were collected in each plot, between plants and in the layers of 0-0.20 and 0.20-0.40 m, to form the composite samples for the analysis of organic matter, pH, H+Al, exchangeable Al and contents of available P, K, Ca, Mg, S, Zn, Cu, Mn, Fe and B (Tedesco et al., 1995; EMBRAPA, 1997). With these data, sum of bases (SB), effective cation exchange capacity ($CEC_{(t)}$), total cation exchange capacity ($CEC_{(T)}$) and base saturation (V) were calculated.

The data were subjected to analysis of variance and the data of sewage sludge doses were adjusted to regression models, testing the coefficients up to 0.10 of probability by t-test. In addition, Pearson's correlation analysis was performed between head diameter and crop yield.

Results and Discussion

Sunflower grain yield increased linearly with the application of increasing sewage sludge doses of up to 30 t ha^{-1} (Table 3). According to Caldeira Júnior et al. (2009) and Nascimento et al. (2014), the increase in yield of plants under sewage sludge application can be attributed to the increase in nutrient availability and the improvement of chemical, physical and biological conditions of soil, caused by the addition of organic matter.

Sunflower stem diameter (SD) increased as sewage sludge doses increased, with the highest value, 34.63 mm, observed for the maximum dose of the residue (Table 3). Guimarães et al. (2009), evaluating initial growth of *Jatropha curcas* as a function of different fertilizer doses and sources, verified higher response for SD at the highest sewage sludge dose, 340 kg ha^{-1}. On the other hand, Prates et al. (2011) did not find increase in SD of *Jatropha curcas* plants fertilized with sewage sludge, in doses of up to 19.2 t ha^{-1}. According to Modesto et al. (2009), the increase in SD reflects the increase in root system, representing a larger soil volume explored by plants, which tend to show better nutritional state and higher water deficit resistance.

Table 3. Regression equations of yield (Y), stem diameter (SD), plant height (PH) and head diameter (HD) of sunflower as a function of the sewage sludge doses applied in the soil

Variable	Fitting equation	R^2	SSD (t ha^{-1})	MV
Y (kg ha^{-1})	Y = 1168.95 + 10.159721***X	0.8918	30.00	1,473.70
SD (mm)	Y = 20.46 + 0.47169***X	0.9984	30.00	34.62
PH (m)	Y = 1.65 + 0.009234***X	0.9881	30.00	1.93
HD (cm)	Y = 15.02 + 0.007049***X^2	0.9288	30.00	21.3

SSD - Sewage sludge dose causing the maximum value of the variable; MV - maximum value of the variable within the experimental interval
***Significant at 0.01 of probability by t-test

There was also linear increase in plant height (PH) with the increase of sewage sludge doses (Table 3). This result agrees with Backes et al. (2009), who obtained linear response of castor bean plants to the application of up to 32 t ha^{-1} of sewage sludge. Zuba Junior et al. (2011) also verified increase in the height of castor bean plants when the maximum dose, 60 t ha^{-1}, was applied. However, Prates (2011) did not find differences in PH of *Jatropha curcas* fertilized with increasing sewage sludge doses of up to 19.2 t ha^{-1}. As previously stated, the higher PH caused by the application of sewage sludge can be explained by the improvement of physical and chemical conditions of soil, which are essential for fast plant growth (Nascimento, 2012).

Similarly to the other biometric characteristics, head diameter (CD) increased as the sewage sludge dose increased (Table 3). These results agree with the ones obtained by Figueiredo et al. (2007), who verified the highest mean values of CD in the treatment with the highest sewage sludge dose, approximately 30.4 t ha^{-1}. Still according to these authors, sewage sludge fertilization increased the availability of nitrogen to sunflower, influencing its head growth. Nobre et al. (2010) pointed out that capitulum growth has direct implications in the potential number of achenes, which confirms the results obtained in this study, with a positive and significant correlation (r = 0.92**) between head diameter and grain yield.

At the end of the cycle, nutrient contents of soil did not vary with the applied sewage sludge doses (Table 4). Similar behavior was observed in sunflower by Nascimento (2012), who found that sewage sludge fertilization did not influence soil content of K, Ca and S. This is possibly related to the slower release of nutrients, since it is an organic residue containing persistent organic substances, and to higher nutrient extraction, because

Table 4. Relationship between soil nutrient content and the applied sewage sludge doses

Nutrient	Layer (m)	Fitting equation[1]	Class[2]
P (mg dm^{-3})	0-0.20	Y = Ym = 29.03	Very good
	0.20-0.40	Y = Ym = 16.92	Good
K (mg dm^{-3})	0-0.20	Y = Ym = 142.25	Very good
	0.20-0.40	Y = Ym = 93.25	Good
Ca ($cmol_c$ dm^{-3})	0-0.20	Y = Ym = 7.88	Very good
	0.20-0.40	Y = Ym = 5.32	Very good
Mg ($cmol_c$ dm^{-3})	0-0.20	Y = Ym = 1.47	Good
	0.20-0.40	Y = Ym = 1.20	Good
S (mg dm^{-3})	0-0.20	Y = Ym = 32.92	Very good
	0.20-0.40	Y = Ym = 36.47	Very good
Cu (mg dm^{-3})	0-0.20	Y = Ym = 0.98	Medium
	0.20-0.40	Y = Ym = 0.76	Medium
Zn (mg dm^{-3})	0-0.20	Y = Ym = 4.77	High
	0.20-0.40	Y = Ym = 1.76	Good
Mn (mg dm^{-3})	0-0.20	Y = Ym = 16.36	High
	0.20-0.40	Y = Ym = 5.77	Medium
Fe (mg dm^{-3})	0-0.20	Y = Ym = 75.60	High
	0.20-0.40	Y = Ym = 60.64	High
B (mg dm^{-3})	0-0.20	Y = Ym = 0.22	Low
	0.20-0.40	Y = Ym = 0.11	Very low

[1]There was no equation fitting with significant coefficients;
[2]Fertility classes according to Alvarez V. et al. (1999); Ym - Mean value

of the high grain yield with the application of sewage sludge. In addition, Nascimento et al. (2011) point out that sewage sludge is an important source of N to plants, but it does not contain the proper amounts of the other nutrients, which makes necessary to complement it with other sources.

Soil K availability in the layers of in 0-0.20 and 0.20-0.40 m was classified as very good and good (CFSEMG, 1999), respectively, before the experiment (Table 1). With the application of 10, 20 and 30 t ha^{-1} of sewage sludge, 25.6, 51.2 and 76.8 kg ha^{-1} of K were added to the soil, respectively. These values are close to or much higher than the amount of K recommended by the CFSMG (2009), which is equal to 24.9 kg ha^{-1} of K_2O. Despite the increase in K amounts added by the sewage sludge, soil K contents were similar in all the treatments (Table 4), but lower than the soil contents before the experiment (Table 1). This can be explained by the fact that K is the element most required by sunflower (Zobiole et al., 2010). However, the classification of very good and good was maintained for the layers of 0-0.20 and 0.20-0.40 m, respectively.

Soil P availability before the experiment (Table 1) was classified as very good and medium (CFSEMG, 1999) for the layers of 0-0.20 and 0.20-0.40 m, respectively. After applying 10, 20 and 30 t ha^{-1} of sewage sludge, 7.7, 15.4 and 23.1 kg ha^{-1} of P were added to the soil, respectively, which are close to or much higher than 13.0 kg ha^{-1} of P, the value recommended by the CFSMG (2009). At the end of the cultivation, regardless of sewage sludge application, soil P availability increased, compared with the condition observed before the experiment, in the layer of 0.20-0.40 m, with a change from medium to good in the classification for this layer (Table 4). These results disagree with the ones obtained by Nascimento (2012), who verified a reduction in the soil contents of available P in the layers of 0-0.20 and 0.20-0.40 m, despite the increase in the applied amounts of P in sunflower cultivation. The author claims that these results can be related to a slower P release, since it is a recalcitrant organic residue, and to a higher nutrient extraction, resulting from higher grain yield.

The application of 10, 20 and 30 t ha^{-1} of sewage sludge added 27, 54 and 81 kg ha^{-1} of Ca to the soil, respectively. The classification of very good and good, in the layers of 0-0.20 and 0.20-0.40 m (Table 1), changed to very good (CFSEMG, 1999) in both layers after sewage sludge application (Table 4). According to Zobiole et al. (2010), Ca is the second most required element by sunflower plants, reaching values close to 116 kg ha^{-1} for a yield of 3.0 t ha^{-1}.

Mg content in before the experiment (Table 1), was classified as very good and good in the layers of 0-0.20 and 0.20-0.40 m, respectively (CFSEMG, 1999). The application of 10, 20 and 30 t ha^{-1} of sewage sludge added 2.7, 5.4 and 8.1 kg ha^{-1} of Mg to the soil, respectively. Mg contents decreased in the layers of 0-0.20 and 0.20-0.40 m (Table 4), compared with the condition before the experiment. The classification, according to CFSEMG (1999), changed from very good to good. Unlike the results obtained in this study, Nascimento (2012) verified increase in soil Mg contents when the maximum sewage sludge dose, 29.04 t ha^{-1}, was applied.

Soil S availability was classified as very good and good in both soil layers (Table 4). Only from the dose of 20 t ha^{-1} on, the applied amount of S reached the value of 30 kg ha^{-1}, recommended by the CFSMG (2009) for sunflower fertilization.

Zn, Mn and Fe contents in soil (Table 4) were classified by CFSEMG (1999) as varying from good, to medium or high, whereas Cu had a medium value and B was classified as low and very low, respectively in the layers of 0-0.20 and 0.20-0.40 m. According to Table 2, all the applied sewage sludge doses provided Zn amounts higher than 4 kg ha^{-1}, the recommended value for sunflower fertilization by the CFSMG (2009).

As for B, even the highest sewage sludge dose added only 0.33 kg ha^{-1} to the soil, which corresponds to approximately 1/3 of the dose for sunflower fertilization recommended by the CFSMG (2009), which is equal to 1 kg ha^{-1}. According to Marchetti et al. (2001), B is essential to sunflower growth and influences its dry matter production, and the highest grain yield was obtained with the dose of 2 kg ha^{-1}.

Fe was the most concentrated microelement in the sewage sludge, with the doses of 10, 20 and 30 t ha^{-1} adding 0.42, 0.84 and 1.26 t ha^{-1} of Fe to the soil (Table 2), which represents a high amount transported to the soil. However, because of its insolubilization reactions under pH closer to alkalinity, the complexing power of organic matter and the fast Fe oxidation when it is released from organic matter, as described by Cunha et al. (2011), no effect was observed on soil with the sewage sludge application (Table 4). Nascimento (2012) found that, although Fe had been the metal in the highest concentration in the sewage sludge, there was no influence of the application of this residue on the available Fe content in the soil.

Soil organic matter, at the end of the cultivation, increased with the sewage sludge doses in the layer of 0-0.20 m (Table 5), reaching its maximum value with the dose of 30 t ha^{-1} of this residue. Similar results were obtained by Nascimento et al. (2004), who verified increase in soil organic matter content with the addition of sewage sludge. Also, soil organic matter content, which were equal to 3.39 and 2.00 dag kg^{-1} in the layers of 0-0.20 and 0.20-0.40 m before the experiment, and classified as medium and low, increased to 3.62 and 2.10 dag kg^{-1}, respectively, resulting in the change of classification for the layer of 0.20-0.40 m from low to medium, according to Alvarez V. et al. (1999). Chiba et al. (2008), studying sugarcane, also verified increase in soil organic matter content with the application of sewage sludge.

Soil pH (Table 5) was not influenced by sewage sludge application at the end of the cultivation. However, the agronomic classification for the layer of 0.20-0.40 m changed from low to high. This increase in the layer of 0.20-0.40 m can be related to the use of calcareous water to irrigate the experiment. These results corroborate the ones obtained by Nascimento (2012), who verified increases in soil pH, compared with the values before the experiment, resulting from irrigation with calcareous water.

The treatments with sewage sludge did not influence the sum of bases (K, Ca and Mg) of the soil at the end of the cultivation (Table 5). However, the mean values observed in the layers of 0-0.20 and 0.20-0.40 m, 9.8 and 6.6 $cmol_c\ dm^{-3}$, respectively, were higher than the ones before the experiment (9.51 and 5.15 $cmol_c\ dm^{-3}$) in these layers, with a change in the agronomic classification for the layer of 0.20-0.40 m, from

Table 5. Relationships between chemical attributes and soil fertility classes with the applied sewage sludge doses

Variable	Layer (m)	Equation	R^2	SSD (t ha^{-1})	MVS	MVY	Class[1]
OM (%)	0-0.20	Y = 2.72 + 0.001338*X^2	0.9922	30.00	3.9	3.9	Medium
	0.20-0.40	Y = Ym = 2.1	-	-	2.1	2.1	Medium
pH	0-0.20	Y = Ym = 6.9	-	-	6.9	6.9	High
	0.20-0.40	Y = Ym = 6.7	-	-	6.7	6.7	High
SB ($cmol_c$ dm^{-3})	0-0.20	Y = Ym = 9.8	-	-	9.8	9.8	Very good
	0.20-0.40	Y = Ym = 6.6	-	-	6.6	6.6	Very good
$CEC_{(t)}$ ($cmol_c$ dm^{-3})	0-0.20	Y = Ym = 9.8	-	-	9.8	9.8	Very good
	0.20-0.40	Y = Ym = 6.6	-	-	6.6	6.6	Good
$CEC_{(T)}$ ($cmol_c$ dm^{-3})	0-0.20	Y = Ym = 10.7	-	-	10.70	10.70	Good
	0.20-0.40	Y = Ym = 8.62	-	-	8.62	8.62	Good
V (%)	0-0.20	Y = Ym = 91.4	-	-	91.45	91.45	Very good
	0.20-0.40	Y = Ym = 75.8	-	-	75.80	75.80	Good
Al^{3+} ($cmol_c$ dm^{-3})	0-0.20	Y = Ym = 0.00	-	-	0.00	0.00	Very low
	0.20-0.40	Y = Ym = 0.03	-	-	0.03	0.03	Very low
H+Al ($cmol_c$ dm^{-3})	0-0.20	Y = Ym = 0.9	-	-	0.9	0.9	Very low
	0.20-0.40	Y = Ym = 2.0	-	-	2.0	2.0	Low

SSD - Sewage sludge dose required to reach maximum concentration in soil; MVS - Maximum value in soil; MVY - Value in soil with the sewage sludge dose for maximum yield; Ym - Mean value; [1]Fertility classes according to Alvarez V. et al. (1999); * Significant at 0.05 of probability by t-test

Table 6. Relationship between nutrient content in sunflower leaves and the applied sewage sludge doses

Nutrient	Equation	R^2	SSD (t ha^{-1})	MCP	NSR[1]	NSR[2]
N (dag kg^{-1})	Y = 3.46 + 0.03625***X	0.9715	30.00	4.54	3.3 - 3.5	-
P (dag kg^{-1})	Y = Ym = 0.57	-	-	0.57	0.4 - 0.7	-
K (dag kg^{-1})	Y = Ym = 2.52	-	-	2.52	2.0 - 2.4	-
Ca (dag kg^{-1})	Y = Ym = 3.17	-	-	3.17	1.7 - 2.2	-
Mg (dag kg^{-1})	Y = Ym = 0.4	-	-	0.4	0.9 - 1.1	-
S (dag kg^{-1})	Y = Ym = 0.3	-	-	0.3	0.5 - 0.7	-
Zn (mg kg^{-1})	Y = Ym = 44.1	-	-	44.1	-	30 - 80
Cu (mg kg^{-1})	Y = Ym = 17.8	-	-	17.8	-	25 - 100
Mn (mg kg^{-1})	Y = Ym = 38	-	-	38	-	10 - 20
Fe (mg kg^{-1})	Y = Ym = 558	-	-	558	-	80 - 120
B (mg kg^{-1})	Y = Ym = 51.4	-	-	51.4	-	35 - 100

SSD - Sewage sludge dose causing maximum nutrient concentration in the plant; MCP - Maximum nutrient content in the plant; [1] Nutrient sufficiency range, according to Malavolta et al. (1997); [2] Nutrient sufficiency range, according to Oliveira (2004); °,*Significant at 0.1 and 0.05 of probability by t-test

good to very good, according to Alvarez V. et al. (1999). This fact can be attributed to a contribution to nutrient supply by the irrigation water, since the increase was also observed in the treatment without sewage sludge application.

Since sewage sludge doses did not influence the contents of exchangeable Al, H+Al and sum of bases in the layers of 0-0.20 and 0.20-0.40 m, no influence was found for $CEC_{(t)}$ and $CEC_{(T)}$ (Table 5).

The treatments with sewage sludge also did not influence V% in the layers of 0-0.20 and 0.20-0.40 m (Table 5), which is related to the lack of influence in sum of bases, $CEC_{(t)}$ and $CEC_{(T)}$, as previously mentioned.

Leaf N content was influenced by sewage sludge application, reaching a value higher than the one considered adequate for the dose of 30 t ha^{-1} (Table 6). Sludge is known to be an important source of N to plants, which is the determinant element in the calculation of fertilization, as established by the CONAMA Resolution nº 375 (Brasil, 2006). However, depending on soil fertility, it usually needs to be complemented by fertilization with other nutrients (Nascimento, 2012).

As observed in the soil, the contents of P, K, Ca, Mg and S in sunflower leaves were not influenced by the application of increasing doses of sewage sludge (Table 6). In spite of that, the contents of P, K and Ca in the plant are considered adequate (Malavolta et al., 1997), while Mg and S remained below the recommended range, evidencing that these two elements can have limited plant growth and development.

As for micronutrients (Table 6), sewage sludge application also did not cause increase in the leaf contents. Except for Cu, all were within the nutrient sufficiency range, according to Oliveira (2004). For Cu, Fe and Mn, similar results were obtained by Lobo & Grassi Filho (2009), which did not find increase in the leaf contents of these elements with the application of sewage sludge. However, these results diverge from the ones obtained by Nascimento et al. (2014), which found increase in the contents of Zn, Mn and Cu in sunflower leaf tissues with the increase in sewage sludge doses. It should be pointed out that, because of the high complexing power of the metals of the organic matter from the sludge, soil pH close to alkalinity, irrigation with calcareous water and high Fe absorption by the plant, the absorption of Cu by the plant might have been inhibited (Malavolta et al., 1997).

The limitation of Mg, S and Cu can explain the linear response of the sunflower yield to the application of increasing sewage sludge doses. In this situation, the Law of the Minimum occurs, where the scarcest nutrient tends to limit plant growth and development. This behavior has been observed in other studies using fertilization with only sewage sludge, like Nascimento (2012).

Conclusions

1. Stem diameter, plant height, head diameter and sunflower yield increased as sewage sludge doses increased.

2. The addition of sewage sludge promotes linear increase in the contents of soil organic matter and N in sunflower leaves.

3. Values of pH, SB, $CEC_{(t)}$, $CEC_{(T)}$, V%, H+Al, exchangeable Al and the contents of available P, K, Ca, Mg, S, Zn, Cu, Mn, Fe and B are not influenced by the application of sewage sludge doses of up to 30 t ha^{-1} in sunflower cultivation.

4. The contents of P, K, Ca, Mg, S, Zn, Cu, Mn, Fe and B in sunflower leaves are not influenced by the application of sewage sludge doses of up to 30 t ha^{-1}.

Acknowledgments

The authors are sincerely thankful to the Minas Gerais Research Support Foundation (FAPEMIG) and to the National Council for Scientific and Technological Development (CNPq), for the financial support, which made this study possible.

Literature Cited

Abreu, M. F. de; Andrade, J. C. de; Falcão, A. de A. Protocolos de análises químicas. In. Andrade, J. C. de; Abreu, M. F. (ed.). Análise química de resíduos sólidos para monitoramento e estudos agroambientais, Campinas: Instituto Agronômico, 2006. Cap. 9, p.121-158.

Alvarez V., V. H.; Novais, R. F.; Barros, N. F.; Cantarutti, R. B.; Lopes, A. S. Interpretação dos resultados das análises de solos. In: Ribeiro, A. C.; Guimarães P. T. G.; Alvarez V. V., V. H. (org.) Recomendações para o uso de corretivos e fertilizantes em Minas Gerais: 5ª aproximação. Viçosa: CFSEMG, l999. Cap.5, p.25-32.

Backes, C; Lima, C. P.; Fernandes, D. M.; Godoy, L. J. G.; Kiihl, T. A. M.; Villas BÔAS, R. L. Efeito do lodo de esgoto e nitrogênio na nutrição e desenvolvimento inicial da mamoneira. Bioscience Journal, v.25, p.90-98, 2009.

Barbosa, G. M. C.; Tavares Filho, J.; Brito, O. R.; Fonseca, I. C. B. Efeito residual do lodo de esgoto na produtividade do milho safrinha. Revista Brasileira de Ciência do Solo, v.31, p.601-605, 2007. http://dx.doi.org/10.1590/S0100-06832007000300020

Brasil. Ministério do Meio Ambiente. Resolução n. 375 de 29 de agosto de 2006. http://www.mma.gov.br/conama/. 01 Nov. 2009.

Caldeira Júnior, C. F.; Souza, R.A.; Santos, A. M.; Sampaio, R. A.; Martins, E. R. Características químicas do solo e crescimento de *Astronium fraxinifolium Schott* em área degradada adubada com lodo de esgoto e silicato de cálcio. Revista Ceres, v.56, p.213-218, 2009.

CFSEMG - Comissão de Fertilidadedo Solodo Estadode Minas Gerais. Recomendação para uso de corretivos e fertilizantes em Minas Gerais: 5ª aproximação. Viçosa, 1999. 359p.

Cunha, E.; Stone, L. F.; Didonel, A. G.; Ferreira, E. P. B.; Moreira, J. A. A.; Leandro, W. M. Atributos químicos de solo sob produção orgânica influenciados pelo preparo e por plantas de cobertura. Revista Brasileira de Engenharia Agrícola e Ambiental, v.15, p.1021-1029, 2011. http://dx.doi.org/10.1590/S1415-43662011001000005

Chiba, M. K.; Mattiazzo, M. E.; Oliveira, F. C. Cultivo de cana-de-açúcar em Argissolo tratado com lodo de esgoto: II., fertilidade do solo e nutrição da planta. Revista Brasileira de Ciência do Solo, v.32, p.653-662, 2008. http://dx.doi.org/10.1590/S0100-06832008000200020

EMBRAPA. - Empresa Brasileira de Pesquisa Agropecuária. Manual de métodos de análise de solo. 2.ed. Riode Janeiro: CNPS, 1997. 212p.

Figueiredo, T. L.; Grassi Filho, H. Níveis de lodo de esgoto na produtividade do girassol. Revista de la Ciência del Suelo y Nutrición Vegetal, v.7, p.16-25, 2007.

Guimarães, A. S; Santos, N. R; Beltrão, N. E. M. Fontes e doses crescentes de adubos orgânicos e mineral no crescimento inicial de pinhão manso. Means Agitat, v.4, p.17-22, 2009.

Lemainski, J.; Silva, J. E. Utilização do biossólido da CAESB na produção de milho no Distrito Federal. Revista Brasileira de Ciência de Solo,v.30, p.741-750, 2006. http://dx.doi.org/10.1590/S0100-06832006000400015

Lobo, T. F.; Grassi Filho, H. Sewage sludge levels on the development and nutrition of sunflower plants. Revista Ciencia del Suelo e Nutricíon Vegetal, v.9, p.245-255, 2009.

Lobo, T. F.; Grassi Filho, H.; Bull, L. T.; Kummer, A. C. B. Efeito do lodo de esgoto e do nitrogênio nos fatores produtivos do girassol. Revista Brasileira de Engenharia Agrícola e Ambiental, v.17, p.504-509, 2013. http://dx.doi.org/10.1590/S1415-43662013000500006

Malavolta, E.; Vitti, G. C.; Oliveira, S. A. Avaliação do estado nutricional das plantas: princípios e aplicações. 2. ed. Piracicaba: POTAFOS, 1997. 319p.

Marchetti, M. E.; Montomya, W. R.; Fabrício, A. C.; Novelino, J. O. Resposta do girassol, *Helianthus annuus*, a fontes e níveis de boro. Acta Scientiarum, v.23, p.1107-1110, 2001.

Modesto, P. T.; Scaroba, M. H.; Helena, M.; Gilberto, C.; Maltoni, C. L.; Cassiolato, A. M. R. Alterações em algumas propriedades de um latossolo degradado com uso de lodo de esgoto e resíduos orgânicos. Revista Brasileira de Ciência do Solo, v.33, p.1489-1498, 2009. http://dx.doi.org/10.1590/S0100-06832009000500039

Nascimento, A. L. Produtividade, nutrição mineral e teores de metais pesados no solo e em girassol adubado com lodo de esgoto. Montes Claros: ICA/UFMG, 2012. 99p. Dissertação Mestrado

Nascimento, A. L.; Sampaio, R. A.; Brandão, D. S.; Zuba Junio, G. R.; Fernandes, L. A. Crescimento e produtividade de semente de mamona tratada com lodo de esgoto. Revista Caatinga, v.24, p.145-151, 2011.

Nascimento, A. L.; Sampaio, R. A.; Zuba Junio, G. R.; Carneiro, J. P.; Fernandes, L. A.; Rodrigues, M. N. Teores de metais pesados no solo e em girassol adubado com lodo de esgoto. Revista Brasileira Engenharia Agrícola e Ambiental, v.18, p.294-300, 2014. http://dx.doi.org/10.1590/S1415-43662014000300008

Nascimento, C. W. A.; Barros, D. A. S.; Melo, E. E. C.; Oliveira, A. B. Alterações químicas em solos e crescimento de milho e feijoeiro após aplicação de lodo de esgoto. Revista Brasileira de Ciência do Solo, v.28, p.385-392, 2004. http://dx.doi.org/10.1590/S0100-06832004000200017

Nobre, R. G.; Gheyi, H. R.; Correia, K. G.; Soares, F. A. L.; Andrade, L. O. Crescimento e floração do girassol sob estresse salino e adubação nitrogenada. Revista Ciência Agronômica, v.41, p.358-367, 2010. http://dx.doi.org/10.1590/S1806-66902010000300006

Oliveira, S. A. Análise foliar. In: Souza, D. M. G.; Lobado, E. (ed.). Cerrado: Correção do solo e adubação. 2.ed. Brasília: Embrapa Informação Tecnológica, 2004. p.245-255.

Prates, F. B. S.; Sampaio, R. A.; Silva, W. J.; Fernandes, L. A.; Zuba Junio, G. R.; Saturnino, H. M. Crescimento e teores de macronutrientes em pinhão manso adubado com lodo de esgoto e silicato de cálcio e magnésio. Revista Caatinga, v.24, p.101-112, 2011.

Ribeirinho, V. S.; Melo, W. J. de; Silva, D. H. da; Figueiredo, L. A.; Melo, G. M. P. de. Fertilidade do solo, estado nutricional e produtividade de girassol, em função da aplicação de lodo de esgoto. Pesquisa Agropecuária Tropical, v.42, p.166-173, 2012. http://dx.doi.org/10.1590/S1983-40632012000200002

Tedesco, M. J.; Volkweiss, S. J.; Bohmen, H. Análise de solo, plantas e outros materiais. 2.ed. Porto Alegre: UFRGS, 1995. 174p. Boletim Técnico, 5

Zobiole, L. H. S.; Castro, C.; Oliveira, F.A.; Oliveira Júnior, A. Marcha de absorção de macronutrientes na cultura do girassol. Revista Brasileira de Ciência do Solo, v.34, p.425-433, 2010. http://dx.doi.org/10.1590/S0100-06832010000200016

Zuba Junio, G. R.; Sampaio, R. A.; Nascimento, A. L.; Lima, N. N.; Fernandes, L. A. Crescimento inicial de mamoneira adubada com lodo de esgoto e silicato de cálcio e magnésio. Revista Caatinga, v.24, p.157-163,2011.