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## As, Cu AND Zn CONCENTRATION IN SANITARY SEWAGE SLUDGE FERTILIZED SOIL AND IN CRAMBE AND CORN GRAINS

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### KEYWORDS

biosolid, *Crambe abyssinica*, organic fertilization, *Zea mays*.

### ABSTRACT

This study aimed to evaluate the total contents of As, Cu and Zn in the profile of a Haplic Cambisol cultivated with crambe and corn and fertilized with sanitary sewage sludge and to compare them with those obtained in other forms of fertilization, as well as the content of metals in the grain of these crops. Two experiments were carried out in the field, one with maize cultivation and another with crambe, both were delineated as randomized blocks with four treatments and six replicates, which were: without fertilization, fertilization with sewage sludge dewatered and dried in the sun, with dry sewage sludge and with mineral fertilizers. At the end of the experiments soil samples were collected at 15, 50, 100, 150 and 200 cm depth for analysis of the total contents of As, Cu and Zn, as well as the grain of the crops. No differences were observed among the treatments. The total contents of As, Cu and Zn in the soil in both experiments and in the corn grains are below the limits of prevention and the maximum limit in grains established by the Brazilian resolutions. In relation to depth, the metal contents in the samples collected from the soil submitted to the fertilization treatments were similar to those quantified in the plots that did not received fertilization, but there was accumulation of Cu and Zn in the upper layers of the soil that received fertilization.

### INTRODUCTION

The advancement of the crisis in water supply, caused by the scarcity of rain and its inadequate use, there is pressure from the society and especially from environmental agencies in the use of techniques that aim at the decontamination of rivers and the treatment of wastewater and sewage. However, this measure generates a by-product called sewage sludge, which, when incorrectly disposed, ends up negatively affecting the environment (Merlino et al., 2010).

A suitable and environmentally correct alternative is the application of sanitary sewage sludge in agricultural and forestry areas, as a soil conditioner and / or organic fertilizer, since it presents in its constitution macro and micronutrients, in addition high organic matter content (Dalpiso et al., 2017; Kummer et al., 2016). However, sewage sludge contains contaminants such as heavy metals, pathogenic organisms and persistent organic compounds. The metals commonly found in sewage sludge

are arsenic (As), cadmium (Cd), lead (Pb), copper (Cu), chromium (Cr), nickel (Ni) and zinc (Zn) (Bettiol & Camargo, 2006).

High levels of heavy metals in sanitary sewage sludge can give the soil high toxicity and make it unfeasible in agricultural, forestry and livestock production areas, which can be accumulated in plant tissues, thus entering the food chain and causing serious damage in animals and humans' health (Rehman et al., 2017).

Heavy metals can be found under five different soil forms, i.e. at different levels of solubility: (a) dissolved; (b) exchangeable; (c) bound to soil structures (specific adsorption); (d) insoluble (forming precipitates). The solubility of metals is dependent on several factors, both the metals and the environment in which they are found. These factors are the metal content, the type of connection they make to the soil, hydrogenionic potential (pH), organic matter (OM) and the cation exchange capacity (CEC) (Zeng et al., 2011).

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Heavy metals, when in the exchangeable and dissolved forms, can leach into the soil profile, contaminating their lower layers and reaching the groundwater, contaminating groundwater and, subsequently, waterways.

Considering the pollutant potential of heavy metals, it is very important to study their behavior in the soil profile fertilized with sanitary sewage sludge. Thus, the objective of this study was to evaluate the total contents of As, Cu and Zn in the profile of a Haplic Cambisol cultivated with crambe and corn and fertilized with sanitary sewage sludge and to compare them with those obtained in other forms of fertilization, as well as the metals' content in the grains of these crops.

## MATERIAL AND METHODS

The experiments were conducted at the experimental farm of the Institute of Agricultural Sciences (ICA) of the Federal University of Minas Gerais (UFMG), Montes Claros campus, from December 2013 to March 2014 with total precipitation of 529.3 mm, an average maximum temperature of 30.4 °C Minimum 20.3 °C and average relative humidity of 66.6% air (INMET, 2013). According to the Köppen classification, the predominant climate in the region is the Aw - tropical savannah, with rainy summer and dry winter. In the experimental areas, samples composed of Cambisol Haplic were collected in the 0-20 cm layer for chemical and physical routine characterization (Table 1) and heavy metal contents (Table 2).

TABLE 1. Chemical and physical attributes of the soil used in the experiment.

Cultivation Area		Attributes <sup>1</sup>											
		pH H <sub>2</sub> O	Pm -----	Prem mg dm <sup>-3</sup> -----	K	Ca	Mg	Al	H + Al	OM	Sand	Silte	Clay
		-----			-----			-----			-----		
		-----			-----			-----			-----		
Corn	Value	8.2	2.61	28.22	249	6.9	1.7	0	9.24	9.68	32	34	34
	Class	VH	VL	-	VG	VG	VG	VL	L	VG	Franco Clayey		
Crambe	Value	7.6	6.07	28.22	249	8.7	1.3	0	1.33	6.44	34	30	36
	Class	VH	VL	-	VG	VG	L	VL	L	L	Franco Clayey		

Pm –Mehlich Phosphor; Prem – Remaining Phosphorus; VH – Very high; VG – Very Good; L –Low; VL – Very Low.

<sup>1</sup> According to Embrapa methodologies (1997).

TABLE 2. Initial total content of heavy metals in the soil and sanitary sewage sludge used in the experiment.

	Attributes		
	As	Cu	Zn
	-----		
	-----		
SSDDS	0.14	158.00	862.20
DSS	0.23	149.00	862.20
Crambe Soil	0.26	13.3	38.13
Corn Soil	0.27	11.6	30.90

DSS – Dry Sewage Sludge; SSDDS – Sanitary sewage sludge dewatered and dried in the sun

The two types of sanitary sewage sludge used were obtained at the Montes Claros Sewage Treatment Plant (STP), operated by the Minas Gerais Sanitation Company (COPASA). At this station, there are reactors for Upflow Anaerobic Sludge Blanket (UASB). The liquid effluents from these reactors follow to aerobic biological filters. In the final stage of sewage treatment, the decantation process occurs, and the water can be released on the stream. The sanitary sewage sludge produced in the anaerobic reactors passes through the centrifugation and heat treatment processes at 350 °C for a period of 30 minutes.

In order to perform this work, the sewage sludge cake was used after its centrifugation and, afterwards, drying in the sun, on a canvas with a layer of 10 cm in height, with this sludge having a water content of about 54 dag kg<sup>-1</sup> and dry sewage sludge, produced at the end of the heat treatment, with water content of approximately 6 dag kg<sup>-1</sup>. The heavy metals detected and quantified in the sewage sludge were As, Cu and Zn and their total contents are presented in Table 2.

The experiments were performed in randomized blocks and consisted in the cultivation of crambe and corn in four treatments and six replications. The fertilization is established according to the nutritional demand of each crop, as shown below. In the cultivation of corn (*Zea*

*mays*) the Dekalb 390 hybrid was used, with an early cycle (115 days), with high resistance to lodging and semi-hard grains, whose fertilization demand is 160 kg ha<sup>-1</sup> of N, 120 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> and 90 kg ha<sup>-1</sup> of K<sub>2</sub>O (Alves et al., 1999). According to this demand and the N content available in the different types of sanitary sewage sludge, the doses were:

T1 – Control (without fertilization);

T2 – Fertilization with sanitary sewage sludge dewatered and dried in the sun (SSDDS) – content of 10.59 kg t<sup>-1</sup>, dry basis, of available nitrogen, providing a dose of 15.11 t ha<sup>-1</sup>;

T3 – Fertilization with dried sewage sludge (DSS) – content of 6.34 kg t<sup>-1</sup>, dry basis, of available nitrogen, providing a dose of 25.25 t ha<sup>-1</sup>;

T4 – Fertilization with NPK – 45 kg ha<sup>-1</sup> of urea, 662.5 kg ha<sup>-1</sup> of single superphosphate and 156.25 kg ha<sup>-1</sup> of potassium chloride, applied in the furrow, and 125 kg ha<sup>-1</sup> of ammonium sulphate and 250 kg ha<sup>-1</sup> of urea, applied as a cover, half of the doses at 30 days of sowing and the other half at 45 days.

Although they present the same origin, the dry sanitary sewage sludge presented lower available N content, this is due to the loss of nitrogen during its drying at 350 °C.

Fertilization in the treatments in which the sewage sludge was applied to the soil was carried out in a single time in the planting furrows. The row spacing was 0.80 m, with 5 seeds per linear meter. The size of each plot was 6.0 x 4.8 m, and the grains were collected from the central 4 m of the rows, eliminating the peripheral rows, as a border.

The crambe (*Crambe abyssinica*) presents a 90-day cycle and was fertilized with 20 kg ha<sup>-1</sup> of N, 40 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> and 20 kg ha<sup>-1</sup> of K<sub>2</sub>O, with formulation adjusted based on the recommendations of Broch et al. (2010). According to the available N content, the following doses were used: without fertilization (T1); 1.89 t ha<sup>-1</sup> of sanitary sewage sludge dewatered and dried in the sun (T2); 3.16 t ha<sup>-1</sup> of dry sanitary sewage sludge (T3); and fertilization with NPK with 120 kg ha<sup>-1</sup> of urea, 600 kg ha<sup>-1</sup> of single superphosphate and 93.3 kg ha<sup>-1</sup> of potassium chloride, applied in the planting furrow (T4).

Fertilization in the crambe crop was done in a single time in the planting furrows. The row spacing was 0.30 m, with 25 seeds per linear meter. Each plot had four rows of 2.5 m long and the useful plot was formed by the 20 central plants, and the borders have been discarded.

Due to the fact that the irrigation system was fixed, taking into account the total area of the experiment, it was not possible to establish specific irrigation management for both crops. Thus irrigation was carried out according to corn crop, being applied a total depth of 490 mm in the area with corn and 367 mm in the crambe planting area, due to the difference in the cultivation period of the crops.

At the end of their cycles, the corn grains were collected from the central plants of the plots (composite sample) and taken to the Laboratory for Analysis of Residues for Agricultural Utilization (LARAA-ICA / UFMG), where they were dried, macerated and submitted to nitric digestion in the Laboratory of Agrochemical Research (LPA-ICA / UFMG), according to the methodology USEPA-3051 (EPA, 1994) in a microwave oven, for later analysis of heavy metals in atomic absorption spectrophotometer. It was not possible to perform the analysis on the crambe grains due to the low development of the crop.

After harvesting, four simple soil samples were collected on the planting lines of the useful areas, composing a composite sample, at depths of 15, 50, 100, 150 and 200 cm, with Dutch traces, and stored in a refrigerator. Subsequently, a portion of each sample was dried in a forced air circulation oven at 65 °C, macerated in a porcelain mortar, passed in 0.5 mm sieve and realizing digestion with 3: 1 royal water (HCl: HNO<sub>3</sub>) in a digestion block for As, Cu and Zn readings in an atomic absorption spectrophotometer (Mcgrath & Cunliffe, 1985). For pH analysis, 10 g of soil was weighed and 25 mL of distilled water was added. After stirring and 1 h rest, the pH was measured (EMBRAPA, 1997).

For the statistical analysis of the soil total metals content it was adopted the split plot scheme, and the types of fertilizers of the main plots and the depths the subplots. The experimental results were submitted to analysis of variance, Tukey's test at 5% of probability and regression with tests of the coefficients up to 10% of probability by t-test, using software R version 3.2.0.

## RESULTS AND DISCUSSION

### Effect of fertilizations on soil pH

There was a reduction in the soil pH in relation to its initial pH (Table 1), mainly in the soil cultivated with corn. At the depth of 15 cm in the soil cultivated with crambe there was a small increase in pH with fertilizations with sanitary sewage sludge and NPK in relation to the treatment without fertilization. On the other hand, in the soil cultivated with corn there was a greater reduction in pH values (Table 3). The reduction in pH of the soil cultivated with corn occurred due to the application of sanitary sewage sludge and chemical fertilizer made at its highest dose, aiming to meet the nutritional demand of N by the crop, resulting in greater availability of nitrogen to be nitrified. Since the corn cultivation may also have caused a reduction in the pH of the control soil by the release of exudates in relation to the initial pH of this soil (Table 1), which may not have occurred in crambe cultivation due to the low development of the crop. In depth, soil pH did not present an adjustment to mathematical models.

TABLE 3. Soil pH cultivated with crambe and corn in different treatments.

Depth (cm)	Crambe			
	WF	SSDDS	DSS	CF
15	7.11 b	7.24 ab	7.36 a	7.24 ab
50	6.58 b	6.67 b	7.06 a	6.92 a
100	5.27 b	5.34 b	5.67 a	5.43 b
150	4.87 b	5.24 a	5.25 a	5.17 a
200	5.26 c	6.03 a	5.58 b	5.49 b
Depth (cm)	Corn			
	WF	SSDDS	DSS	CF
15	7.14 a	6.75 b	6.57 b	6.53 b
50	6.05 b	7.44 a	6.21 b	5.58 c
100	4.93 b	5.41 a	5.34 a	5.16 ab
150	4.99 a	4.68 b	4.76 ab	4.82 ab
200	6.00 a	5.63 b	5.54 b	5.67 b

WF – Without fertilization (control); SSDDS – Sewage sludge dewatered and dried in the sun; DSS - Dry Sewage Sludge; CF – Chemical fertilization. Means followed by the same letter, lowercase in horizontal, do not present significant differences between them, by Tukey test at 5% probability.

Nitrogen fertilization provides soil acidification by nitrification of ammonium, with production of two protons ( $H^+$ ) for each  $NH_4^+$  nitrified (Costa et al., 2008). The application of sanitary sewage sludge provides immobilization and nitrogen nitrification (Antoniadis et al., 2008), oxidation of sulfides (Souza et al., 2012) in the sludge and the formation of organic acids in the organic matter degradation process by microorganisms (Villanueva et al., 2012). These processes can still be accelerated when under tropical climate conditions, where there is more activity and microbial biomass in the soil (Antoniadis et al., 2008), being the condition in which the experiment was conducted, thus accelerating the process of organic matter decomposition of the sludge, and initially releasing organic acids and  $H^+$  ions in the medium. However, as the sanitary sewage sludge mineralizes, the release of salts in the medium occurs, which can raise soil pH (Gondek et al., 2018).

#### Total content of As, Cu and Zn in sanitary sewage sludge and soil cultivated with crambe and corn

TABLE 4. Total As, Cu and Zn contents in soil cultivated with crambe and corn in different treatments.

Treatments	Soil cultivated with crambe			Soil cultivated with corn		
	As	Cu	Zn	As	Cu	Zn
	----- mg kg <sup>-1</sup> -----					
WF	0.69 a	14.62 a	61.67 a	0.78 a	17.78 a	29.63 a
SSDDS	0.87 b	15.25 a	59.10 a	0.79 a	19.69 a	37.46 a
DSS	0.92 b	14.72 a	73.40 a	0.81 a	19.80 a	36.94 a
CF	0.90 b	14.67 a	67.28 a	0.79 a	18.40 a	33.18 a
CV (%)	9.85	6.26	14.17	14.17	11.47	18.38

WF – Without fertilization (control); SSDDS – Sewage sludge dewatered and dried in the sun; DSS - Dry Sewage Sludge; CF – Chemical fertilization.

Means followed by the same letter, lowercase in horizontal, do not present significant differences between them, by Tukey test at 5% probability.

The quality reference value (QRV) corresponds to the state of natural occurrence of an element / chemical substance in the soil and is defined by the environmental organs of each state (Brasil, 2009). In the State of Minas Gerais, the QRV for As is 8.0 mg kg<sup>-1</sup> (Minas Gerais, 2011), thus much higher than that found in soils of the experimental area, even those that were fertilized. The Cu and Zn QRVs are 49.0 and 46.5 mg kg<sup>-1</sup> (Minas Gerais, 2011), respectively, so the total contents of Cu and Zn are considered to be naturally occurring, except only for Zn in soil cultivated with crambe, being above the established limit, including for the treatment without fertilization, and it is recommended the verification of QRVs. However, the total contents of As, Cu and Zn in the soil are below the prevention value (PV) of 15; 60 and 300 mg kg<sup>-1</sup>, respectively (Minas Gerais, 2011). The PV is characterized

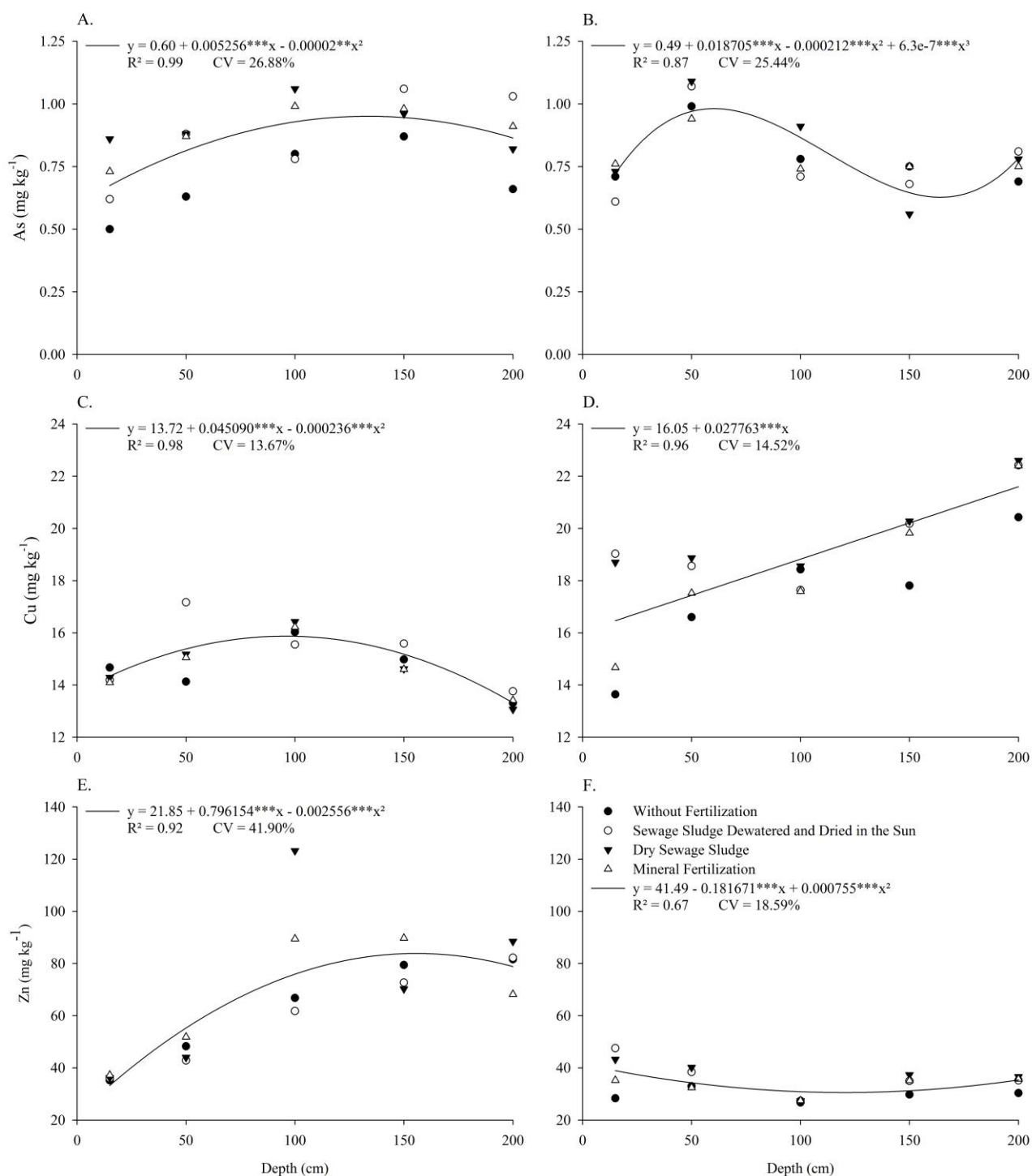
The CONAMA Resolution No. 375 of 2006 provides that the maximum total content of As, Cu and Zn in sanitary sewage sludge is 41; 1,500 and 2,800 mg kg<sup>-1</sup>, respectively (Brasil, 2006), these limits much higher than those found in sanitary sewage sludge used in this study (Table 2). Nascimento et al. (2014) also found lower total contents of Cd, Cr, Cu, Ni, Pb and Zn in relation to the legislation for sanitary sewage sludge, under different stabilization processes, to be used in agricultural cultivation areas.

As there was no significant interaction between fertilization types and soil depth ( $p > 0.05$ ), the effect of fertilization types and depths on total As, Cu and Zn levels in the soil was analyzed separately. In relation to the types of fertilization, a significant statistical difference was observed only in relation to the total content of As in the soil cultivated with crambe, and the control presented a total As content lower than that obtained in the other treatments (Table 4). This may have occurred due to the application of As by the fertilizers used.

as the total limiting content of a particular element / chemical substance in the soil, without losing the capacity to sustain its main functions (Brasil, 2009).

Analyzing the total levels of As, Cu and Zn in the soil profile, statistical significance was observed for soil cultivated with crambe and corn, thus adjusting regression models (Figure 1), showing trend along with the means of the treatment without fertilization (control), evidencing again the natural occurrence of these metals in the soil.

In the soil cultivated with crambe (Figure 1A), there was a quadratic response with a maximum total content of 0.94 mg kg<sup>-1</sup> to 130 cm of depth, whereas in the soil cultivated with corn there was a cubic response, with a maximum content of 0.98 mg kg<sup>-1</sup> at 60 cm and a minimum of 0.63 mg kg<sup>-1</sup> at 164 cm of depth.



\*\*\*, \*\* – Significant by T test at 0.1 and 1% probability, respectively.

FIGURE 1. Behavior of the total content of As, Cu and Zn on soil fertilized with sewage sludge in crambe (A, C and E) and corn culture (B, D and F).

For the soil cultivated with crambe, there was a quadratic response in the total Cu content with a maximum of 15.87 mg kg<sup>-1</sup> in depth of 96 cm (Figure 1C), whereas for the soil cultivated with corn, the response was linearly increasing (Figure 1D). It was also observed that the total content of Cu in the soil profile cultivated with corn was higher than that cultivated with crambe, this was due to the greater application of the fertilizers to meet the nutritional demand of N of the corn crop. As a consequence, it was also observed that there was an increase from 13.64 to 19.03 and 18.70 mg kg<sup>-1</sup>, an increase corresponding to 39.5 and 37.1% for SSDDS and DSS, respectively, in the total

content of Cu at the depth of 15 cm and of 16.60 to 18.56 and 18.87 mg kg<sup>-1</sup>, increment corresponding to 13.6 and 11.8% for SSDDS and DSS, respectively, at depth of 50 cm in relation to the treatment without fertilization (Figure 1D).

The accumulation of Cu in the 15 and 50 cm layers of the soil is due to the strong connections with the clays and organic matter of the soil, resulting in lower leaching risks of the metal in the soil profile and, consequently, losses to the groundwater (Souza et al., 2012; Singh & Kalamdhad, 2013). In addition, Oliveira et al. (2018), using dry sanitary sewage sludge from the same STP

supplier of the residue used in this study, obtained, by sequential extraction, that 90.5% of Cu was found bound to stable fractions, such as carbonates, organic matter, sulphides and residual, whereas only 9.5% was in the soluble and exchangeable form.

The total Zn content obtained in the soil cultivated with crambe (Figure 1E) was higher than the soil cultivated with corn (Figure 1F), even with the greater application of sanitary sewage sludge and fertilizer in that soil. This may have occurred due to the low development of crambe plants, compromising the absorption of metals by the plant, maintaining its content at the end of the crop. On the other hand, the corn presented a good development, and then have absorbed the Zn and stored it in its organism, although the content of the metal in the aerial part and in the root of the plants has not been analyzed separately, so that can be confirmed. However, Oliveira et al. (2005) concluded that the content of heavy metals, including Zn, is higher in the leaves than in the corn grains.

Regarding the Zn content in depth in the soil cultivated with corn, there was a quadratic response with a minimum content of 30.56 mg kg<sup>-1</sup> at 120 cm depth, however, in the depth of 15 cm there was accumulation of 47.55; 43.25 and 35.24 mg kg<sup>-1</sup>, increase corresponding to 67.7; 52.6 and 24.3% of the total Zn content in the soil submitted to treatment with addition of SSDDS, DSS and CF, respectively, in comparison with the non-fertilization, with a content of 28.34 mg kg<sup>-1</sup>. In the soil cultivated with crambe, a high accumulation of zinc was observed in its profile, with 83.85 mg kg<sup>-1</sup> being accumulated at 155 cm depth, according to the adjusted model. In the treatment with dry sanitary sewage sludge, there was a higher accumulation, with a total content of 123.18 mg kg<sup>-1</sup> at 100 cm depth, corresponding to approximately twice the content of 66.8 mg kg<sup>-1</sup> observed in the treatment without fertilization at the same depth (Figure 1E).

Oliveira et al. (2018) studying the Zn speciation in dry sanitary sewage sludge, obtained that 4.9% of the Zn was in soluble and exchangeable form, justifying, in part, the metal leaching to a depth of 100 cm.

In some studies, Zn is highly mobile in the soil profile and normally its mobility and / or adsorption is related to soil pH variations (Abat et al., 2012; Huang et al., 2014). These authors explain that in acidic soils there is an abundance of free H<sup>+</sup> ions, competing with the metals for the soil binding sites, reducing their adsorption. On the other hand, in alkaline soils there is attenuation of the competition, increasing the adsorption of the metals in the soil.

Huang et al. (2014) obtained an increasing linear response of Cu and Zn adsorption in soil with increasing values of pH, proving that the higher the pH of the soil, the greater its adsorptive power. This explains the higher content of these elements in the upper layers of the soil, especially those cultivated with corn and fertilized with sanitary sewage sludge, where there was greater application of the fertilizer. However, Fang et al. (2016) report that with the increase of the dissolved organic matter in the soil, by the application of sanitary sewage sludge, significantly increased leaching of heavy metals in pH between 6 and 8. This would explain the Zn leaching at 100 cm depth in soil cultivated with crambe, because this soil had higher pH values (Table 3).

A possible solution to decrease the content of metals in depth is the use of crops, rotating or not, that have a deep root system, and can thus favor the cycling and / or export of the elements. In addition to recommending constant monitoring of the sanitary sewage sludge application areas, in order to verify if there is an increase in heavy metal levels in the soil and consequent environmental damage.

### Total content of As, Cu and Zn in corn grains

The crambe crop presented limited development, due to the rainfall intensity and the high relative humidity of the air in the period of the experiment implantation, which were 196.30 and 414.70 mm and 61.53 and 81.01% (INMET, 2013), respectively, for the months of November and December of 2013. The crambe crop does not tolerate rainy periods and high relative humidity, as stated by Falasca et al. (2010). Glaser (1996) also emphasizes that the high content of water in the soil can cause diseases such as alternaria (*Alternaria brassicicola*) and white mold (*Sclerotinia sclerotiorum*). Thus, there was no adequate development of the crambe plants, and it was not possible to quantify As, Cu and Zn contents in the grains and in the rest of the biomass.

Table 5 shows the Cu and Zn content in the corn grains, and As was not detected in the grains. However, no significant statistical difference was found among the different treatments in relation to Cu and Zn contents. For the Cu, there was a great variation among the repetitions, which caused in the increase of the CV.

TABLE 5. Cu and Zn content of corn grains cultivated on soil fertilized with sanitary sewage sludge.

Treatments	Cu	Zn
	----- mg kg <sup>-1</sup> -----	
WF	10.15 a	37.80 a
SSDDS	9.72 a	40.39 a
DSS	10.86 a	38.60 a
CF	11.29 a	41.04 a
CV (%)	76.79	20.36

WF – Without fertilization (control); SSDDS – Sewage sludge dewatered and dried in the sun; DSS - Dry Sewage Sludge; CF – Chemical fertilization.

Means followed by the same letter, lowercase in horizontal, do not present significant differences between them, by Tukey test at 5% probability.

Evaluating the effect of the sanitary landfill residue on the heavy metal content of corn, Prabhari et al. (2009) observed that there was a positive correlation between the soil metal content and the corn grains for As, Cd, Cu and Zn, but not significant for Cu and Zn. However, Zn was more likely to be accumulated in corn grains. However, Bai et al. (2017) found that the addition of sanitary sewage sludge in increasing doses (0, 30, 75, 150 and 300 t ha<sup>-1</sup>) had no influence on Cu content, but in the Cd and Ni contents and that there was increase for Cr, Zn and Mn only in the higher doses in the corn grains, however, no metal exceeded the food limits, as observed in this study.

The Decree No. 55.871 of 1965 (ANVISA, 1965) establishes the maximum tolerance limits (MTL) of 30 and 50 mg kg<sup>-1</sup> of Cu and Zn, respectively, in dry matter of food. Based on this decree, the Zn and Cu contents in the corn grains are below the maximum tolerance limits.

Nogueira et al. (2008) studying the heavy metals content in soil and corn plants after nine years of annual application of increasing doses of sanitary sewage sludge (45, 90 and 127.5 t ha<sup>-1</sup>), they found results similar to those of the present study, wherein the Zn content in the corn grain was below the ANVISA (1965) maximum tolerance limits.

According to Kabata-Pendias (2011), the metals' absorption by the plants varies with the type of the element, being the Cu and Zn actively absorbed by the roots and in a similar way, consequently, the behavior of these metals are antagonistic by competitively inhibiting the absorption of the other. The author also points out that the roots and their association with soil microorganisms are able to produce organic substances efficient in the release of heavy metals adsorbed on the soil particles, potentializing their absorption.

It is noteworthy that Cu and Zn are also micronutrients that are part of a series of plant metabolic processes. Thus, the high incorporation of these to the soil by the continuous application of sanitary sewage sludge must be controlled, as it may present risk to the plant due to high absorption and, consequently, nutritional imbalance and, later, phytotoxic effects.

## CONCLUSIONS

The total contents of As, Cu and Zn were similar in the treatments in which the soil was only receiving the chemical fertilization and in those in which sanitary sewage sludge was applied, having accumulation of Cu and Zn in the upper layers of the soil that received both chemical fertilization as sanitary sewage sludge.

The total Cu and Zn contents in corn grains were not influenced by the application of up to 25 t ha<sup>-1</sup> of sanitary sewage sludge and remained below the maximum limit allowed by current legislation.

The disposal of sanitary sewage sludge in agriculture, especially as regards grain production, it may be adequate and a sustainable measure when considering the issue of accumulation in the soil and contamination of the product with heavy metals in application done in a single period of the culture.

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