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Biosolids as fertilizer in the tomato crop

Biosólidos como fertilizante en el cultivo de tomate

Biossólidos como fertilizante na cultura do tomate

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Abstract

The sludge produced in wastewater treatment plants constitutes a potential alternative to replace traditional fertilizers and reduce costs in agricultural activities. The objective of this work was to compare the fertilizing effect of the sludge produced in the wastewater treatment plant of Sotaquirá-Colombia, with the fertilizers traditionally used on the tomato crop (*Solanum lycopersicum* L*)*. For this, the sludge was previously stabilized with two different treatments: dehydration and the addition of CaO. Subsequently, four treatments were applied to the tomato seedlings, 135 $g.kg^{-1}$ of dehydrated biosolid, 135 $g.kg^{-1}$ biosolid stabilized with CaO, 135 $g.kg^{-1}$ of ABIMGRA®, 135 $g.kg^{-1}$ of naturcomplet®-G, and greenhouse soil without biosolids. The height of the plant, the fresh and dry mass, foliar area, and fruits per plant, were measured at 0, 30, 60 and 90 days after sowing. In tomato fruits, the concentrations of heavy metals, coliforms, helminth eggs, somatic phages, and *Salmonella* sp., were determined. The dehydrated biosolids had a significant effect on the size, the fresh mass, foliar area, and the number of fruits per plant, compared to the alkaline biosolids. The dry mass of the plants (120 g. $plant^{-1}$) was similar to traditional fertilizers and biosolids. Tomatoes produced with biosolids had low levels of heavy metals and an absence of pathogenic microorganisms. In conclusion, the biosolid obtained by dehydration in Sotaquirá can be used as a potential fertilizer in tomato cultivation.

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Resumen

Los lodos producidos en las plantas de tratamientos de aguas residuales constituyen una alternativa potencial para reemplazar fertilizantes tradicionales y disminuir costos en las actividades agrícolas. El objetivo de este trabajo fue comparar el desempeño de los lodos producidos en la planta de tratamiento de aguas residuales de Sotaquirá-Colombia, con los fertilizantes tradicionalmente empleados sobre el cultivo de tomate (*Solanum lycopersicum* L.*)*. Para ello, los lodos fueron previamente estabilizados con dos tratamientos diferentes: deshidratación y adición de óxido de calcio (CaO). Posteriormente, cuatro tratamientos fueron aplicados en plántulas de tomate, 135 $g.kg^{-1}$ de biosólido deshidratado; 135 $g.kg^{-1}$ biosólido estabilizado con CaO; 135 $g.kg^{-1}$ de ABIMGRA®, 135 $g.kg^{-1}$ de naturcomplet®-G y suelo del invernadero sin biosólidos. La altura de la planta, la masa fresca y seca, el área foliar y frutos por planta, se midieron a los 0, 30, 60 y 90 días después de la siembra (DDS). En los frutos de tomate se determinaron las concentraciones de metales pesados, coliformes, huevos de helmintos, fagos somáticos y *Salmonella* sp. Los biosólidos deshidratados tuvieron un efecto significativo mayor sobre el tamaño, la masa fresca, el área foliar y el número de frutos por planta, comparado con los biosólidos alcalinos. La masa seca de las plantas (120 g. $plant^{-1}$) fue similar con fertilizantes tradicionales y biosólidos. Los tomates producidos con los biosólidos presentaron niveles bajos de metales pesados y ausencia de microorganismos patógenos. En conclusión, el biosólido obtenido por deshidratación en Sotaquirá, puede ser empleado como potencial fertilizante en el cultivo de tomate.

Palabras clave: lodos de aguas residuales; enmiendas; *Solanum lycopersicum*; patógenos; inocuo.

Resumo

O lodo produzido nas estações de tratamento de efluentes constitui uma alternativa potencial para substituir os fertilizantes tradicionais e reduzir custos nas atividades agrícolas. O objetivo deste trabalho foi comparar o efeito fertilizante do lodo produzido na estação de tratamento de águas residuárias de Sotaquirá-Colombia, com os fertilizantes tradicionalmente usados na cultura do tomate (*Solanum lycopersicum* L*)*. Para isso, o lodo foi previamente estabilizado com dois tratamentos distintos: desidratação e adição de CaO. Seguidamente, foram aplicados quatro tratamentos as mudas de tomate, 135 $g.kg^{-1}$ de biossólido desidratado, 135 $g.kg^{-1}$ de biossólido estabilizado com 13% CaO, 135 $g.kg^{-1}$ de ABIMGRA®, 135 $g.kg^{-1}$ de naturcomplet ®-G, e solo de estufa sem biossólidos. A altura da planta, a massa fresca e seca, a área foliar, o número de ramos, folhas e frutos por planta foram medidos aos 0, 30, 60 e 90 dias após a semeadura DAS. Em frutos do tomate, foram determinadas as concentrações de metais pesados, coliformes, ovos de helmintos, fagos somáticos e *Salmonella* sp. O biossólido desidratado teve efeito significativo sobre o tamanho, a massa fresca, a área foliar e o número de frutos por planta, quando comparado com biossólido alcalino. A massa seca das plantas (120 g. $plant^{-1}$) foi semelhante com fertilizantes tradicionais e biossólidos. Os tomates produzidos com biossólidos apresentam baixos teores de metais pesados e ausência de microrganismos patogênicos. Em conclusão, o biossólido obtido por desidratação em Sotaquirá pode ser utilizado como potencial fertilizante na cultura do tomate.

Palavras-chave: lodo de esgoto; emendas; *Solanum lycopersicum*; patógenos; inócuo.

Introduction

Tomato is one of the most important vegetables in the world. In Colombia, the Department of Boyacá is the first tomato producer reaching up to 100 t. ha^{-1} (Agro Bayer Colombia, 2019). The acidity of the soil, the fertilization, and the pests, are the main factors that limit the agricultural production of tomatoes in Colombia (Herrera & Pérez, 2020). ABIMGRA® and naturcomplet®-G, are fertilizers most commonly used in tomato cultivation in Boyacá, Colombia. However, these fertilizers are expensive. ABIMGRA® is an integral soil fertilizer, enriched with substances that facilitate the transport of nutrients through the vascular system of the plant (ABIMGRA, 2020). Naturcomplet®-G is a soil improver obtained from leonardite, a rich source of humics acids (Naturezza, 2020). At a global level, the possibility of using biosolids (stabilized sewage sludge) as fertilizer has been evaluated on several crops such as tomatoes (Otieno *et al*., 2020), wheat (Dad *et al*., 2018), corn (Giannakis *et al*., 2020), radish (Silva-Leal *et al*., 2013b), and sugar cane (Torres *et al*., 2015). The results indicate that some biosolids can be used to improve soil structure, reduce the use of chemical fertilizers, optimize costs, and increase crop yields (Chow & Pan, 2020). The biosolids can arrive safely due to stabilization treatments, which eliminate pathogenic microorganisms (Silva-Leal *et al*., 2013a).

The wastewater treatment plant located in Sotaquirá, Boyacá, Colombia produces 109 tons of sludges per year. The sludges of Sotaquirá have been stabilized by alkalization and dehydration in the drying bed (Castellanos *et al*., 2020). The microbiological and physicochemical characterization of these biosolids suggests potential agricultural use due to their high content of total organic matter and low levels of heavy metals (Castellanos *et al*., 2018). The high levels of phosphorus, organic carbon, and nitrogen are attributable to the main local economic activity of the municipality, which is the production of artisanal dairy products. However, the fertilizing power of these biosolids has not been tested in any crop. There are also no studies where the effect of biosolids is compared with traditional fertilizers in tomato crops. The objective of this study was to compare the effect of the use of biosolids stabilized with lime (CaO) and by natural dehydration in drying beds produced at the wastewater treatment plant of the Sotaquirá, with traditional fertilizers ABIMGRA and Naturcomplet®-G in the growth of tomato plants (*Solanum lycopersicum* L). In addition, it was evaluated that the tomatoes harvested with bisolids were safe for consumption.

Materials and methods

Study area

The study was carried out at the Wastewater Treatment Plant (WTP) of the municipality of Sotaquirá, Colombia, located at 5°45'54"N, 73°14'53"W at 2628 meters above sea level (masl). The average annual temperature is 14°C (between 7 and 20°C) with average annual relative humidity of 80%, average annual precipitation of 1260 mm, and average wind speed of 21 $km.h^{-1}$. The main economic activity is dairy production and all its discharges flow into the sewage system. The wastewater treatment plant treats an average flow of 1.72 L. s^{-1} (Castellanos *et al*., 2018).

Sewage sludge stabilization treatment

To obtain dehydrated biosolid, the sludge was deposited forming a 30-centimeter layer in a 10 m^2 drying bed covered with a polypropylene roof, and it was dried for five months. Later it was macerated and sifted through an ASTM sieve (16 mesh) with a 1.18 mm diameter opening in stainless steel (Endecotts brand). Alkaline biosolid was obtained using lime, briefly the sewage sludge was drying in an oven at 44°C for 24 h mixed homogeneously with CaO (99% analytical grade) at 13% (w/w) and sifted through an ASTM sieve (16 mesh) with a 1.18 mm diameter opening in stainless steel (Endecotts brand). After that, 100 g of biosolids were collected by triplicate for physical-chemical characterization. For biosolids, ABIMGRA, Naturcomplet®-G, and greenhouse soil, the total concentrations of heavy metals (As, Cd, Cu, Cr, Mo, Ni, Pb, Se, Hg and Zn) were analyzed by extraction acid and quantified by atomic absorption spectrometry (EPA, 1996). Soil organic carbon (ICONTEC, 2006), available phosphorus (García & Ballesteros, 2006), total nitrogen (TC WI: 2003 E), pH (EPA, 2004), electrical conductivity (EPA, 1982), soil humidity (ICONTEC, 2013), fecal coliforms (Castellanos *et al*., 2020), *Salmonella* sp., (EPA, 2006), helminth eggs (Rachel & Duncan, 1996), and somatic phages (Lasobras *et al*., 1999) also were determined.

Application of biosolids to tomato seedlings

The experiment was performed in a greenhouse in the municipality of Santa Sofía-Boyacá-Colombia, located at 5°42′49″N, 73°36′11″W at 2353 masl. The average annual temperature is 14°C (between 8 and 18°C) with average annual relative humidity of 73%, and average annual precipitation of 1179 mm. The sowing of the seedlings (*Solanum lycopersicum* L.) was carried out with a completely randomized experimental design with 30 repetitions (seedlings) for each treatment. Four treatments were evaluated: the soil was mixed with I. 135 $g.kg^{-1}$ of biosolid stabilized by natural dehydration for five months, II. 135 $g.kg^{-1}$ of biosolid stabilized with CaO at 13% III. 135 $g.kg^{-1}$ of ABIMGRA®, and IV. 135 $g.kg^{-1}$ of Naturcomplet®-G (Utria *et al*., 2008). The seedlings were sown with each treatment in black high-density polyethylene plastic bags. One month after sowing to the greenhouse the plants were transplanted. The distance between plants was 0.4 m and between rows 1 meter to obtain a population density of 2.5 $plants.m^{-2}$ (Arévalo & Castellano, 2009). Plant height, fresh mass, dry mass, foliar area, and number of fruits were measured in three plants per treatment at 0, 30, 60, and 90 days after sowing. The plant physiological growth rates of the plants were calculated as the relative growth rate (RGR), leaf area index (LAI), crop growth rate (CGR), absolute growth rate (AGR) at 0, 30, 60, and 90 days of culture (Gardner *et al*., 2003).

Chemical and microbiological analysis of tomato fruits

Parameters such as K, Ca, Mg, Na, S, Fe, Cu, Mn, Zn were extracted by acid nitric: peroxide: water (5:1:2) digestion and quantified by atomic absorption spectrometry. Others like As, Cd, Cr, and Pb were extracted by acid nitric: peroxide: water (5:1:2) digestion and quantified by inductively plasma emission spectrometry (EPA, 1996). Boron was determined by NTC 5404 modified (ICONTEC, 2011). Likewise, nitrogen total, available phosphorus, fecal coliforms, *Salmonella* sp., helminth eggs, and somatic phages were determined as described above.

Statistical analysis

To determine significant differences between treatments of fertilization, analysis of variance and the Tukey test was applied with a 95% confidence interval using the InfoStat program (Di Rienzo *et al.,* 2020).

Results and discussion

Sewage sludge stabilization treatment

The biosolids obtained from two treatments contain concentrations of metals lower than the limits allowed for agricultural use (Table 1). Total organic carbon (37%), available phosphorus (5.1%), and nitrogen (2.1%) of the biosolids obtained by dehydration were higher than the values reported for other biosolids, fertilizers, and organic amendments used for improvement of agricultural soils (Romanos *et al*., 2019; Silva-Leal *et al*., 2013a). Therefore, drying did not affect the chemical properties of the biosolids. The dehydrated sludges presented low levels of fecal coliforms, helminth eggs, and somatic phages, which indicates that these can be used in agriculture with some restrictions (table 1).

On the other hand, the treatment with CaO increased pH, electrical conductivity, concentration of organic carbon, and decreased the total phosphorus available and total nitrogen of the biosolids (table 1). These results are in agreement with those reported by Castellanos *et al*., 2020), Méndez *et al*. (2002), and Silva-Leal *et al*. (2013a). Likewise, the treatment with CaO at 13%, eliminated coliforms, *Salmonella* sp., helminth eggs, and somatic phages, similar to the results reported by Torres *et al*. (2009). Studies have been reported that some environment conditions such as temperature, humidity, solar radiation could be lethal for survival of pathogenic microorganisms (Ibenyassine *et al*., 2007). Considering the height (2860 m) of Sotaquirá, ultraviolet radiation is quite high throughout the year, therefore ultraviolet light could directly influence the reduction of pathogens in dehydrated biosolids. Regarding alkaline lime treatment, the addition of lime to sludge is known to inactivate or kill pathogenic bacteria by raising the pH above 12 and the temperature above 55°C (Hansen *et al*., 2007).

Effect of biosolids on tomato seedlings

The effect on the growth of tomato seedlings when using biosolids and traditional fertilizer (ABIMGRA and Naturcomplet®-G) was positive in all parameters evaluated. The treatment with traditional fertilizer increased height, fresh mass, and fruits compared to alkaline and dehydrated biosolid treatment. However, dry mass was similar using dehydrated biosolid or Naturcomplet®-G and ABIMGRA® (figure 1b).

Additionally, fresh mass, height, dry mass, and fruits of the plants treated with dehydrated biosolids were greater than alkaline biosolid. According to Julca *et al*. (2006), the application of dehydrated sludge with high concentrations of organic matter, phosphorus, and nitrogen, increases the cation exchange, improves the structure and texture of soils, and the assimilation of nutrients by plants (Arévalo & Castellano, 2009). The sludge with CaO at 13% decreases the pathogenic microorganisms and corrects the acidity of the soil. However, some studies indicated that high calcium concentrations reduce the availability of zinc, boron, iron, manganese, lead, and copper, phosphorus and nitrogen which limits the growth of plants (Opala *et al*., 2018; Barrow, 2017; Méndez *et al*., 2002). Calcium oxide decreases the acquisition of various diseases due to the composition of the cell walls preventing the penetration of pathogens into the host plant. (Andersen *et al*., 2018; Li & Zou, 2017). However, high concentrations of calcium oxide (CaO) can cause alkali damage. These damages vary according to the type of plant and range from chlorosis, atrophy, scorching of the leaves, or wilting to the destruction of seedlings and young plants (Sharma *et al*., 2020). The effect of the biosolids on the growth of tomato plants was corroborated by calculating physiological growth indexes (data

Table 1. Physicochemical and microbiological parameters of the biosolids, ABIMGRA and Naturcomplet®-G fertilizers, and greenhouse soil (negative control).

Parameters	Dehydrated biosolid	Alkaline Biosolid	ABIMGRA	Naturcomplet®-G	Control soil	Biosolid Type A*	Biosolid Type B*
Arsenic ($mg.kg^{-1}$)	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.1	<1.8 ± 0.1	<1.8 ± 0.1	20	40
Cadmium ($mg.kg^{-1}$)	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.1	8	40
Copper ($mg.kg^{-1}$)	<18 ± 0.0	<18 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.0	1.9± 0.0	1000	1750
Chrome ($mg.kg^{-1}$)	<18 ± 0.0	<18 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.1	1000	1500
Mercury ($mg.kg^{-1}$)	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.1	10	20
Molybdenum ($mg.kg^{-1}$)	<40 ± 0.0	<40 ± 0.0	<40 ± 0.0	<40 ± 0.0	<40 ± 0.0	18	75
Nickel ($mg.kg^{-1}$)	<18 ± 0.0	<18 ± 0.0	<18 ± 0.0	<18 ± 0.0	<18 ± 0.0	80	420
Lead ($mg.kg^{-1}$)	<18 ± 0.0	<18 ± 0.0	<18 ± 0.0	<18 ± 0.0	<18 ± 0.0	300	400
Selenium ($mg.kg^{-1}$)	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.0	<1.8 ± 0.0	<18 ± 0.0	36	100
Zinc ($mg.kg^{-1}$)	82.0 ± 0.1	82.0 ± 0.0	<1.8 ± 0.0	ND	2.79 ± 0.0	2000	2800
Organic carbon (%)	37.3 ± 1.5	44.6 ± 2.3	10.9	20.3	5.04 ± 0.0	N/A	N/A
Phosphorus (%)	5.1 ± 0.1	0.2 ± 0.0	2.3	ND	22 ± 0.0	N/A	N/A
Nitrogen (%)	2.1 ± 0.6	1.1 ± 0.0	1.1	1.0± 0.0	0.4± 0.0	N/A	N/A
Humidity (%)	6.0 ± 0.0	ND	12.6	30± 0.0	35± 0.0	N/A	N/A
pH	6.5 ± 0.1	12.0 ± 0.1	6.8	8.7± 0.0	4.95± 0.0	N/A	N/A
Electrical conductivity ($Ds.m^{-1}$)	0.6 ± 0.1	4.3 ± 0.2	38.9	2.5	0.3	N/A	N/A
Salmonella sp.25 g^{-1}	A	A	A	A	ND	A	<3
Coliforms (Log $CFU.g^{-1}$)	3.0 ± 0.0	0	<3	<3	<3	<3	<6.3
Helminths (eggs.4 g^{-1})	1.0 ± 0.6	0	<1	<1	<1	<1	<10
Phages (Log $PFU.g^{-1}$)	3.7 ± 0.1	0	<4.7	<4.7	<4.7	<4.7	ND

*MVCT, 2014. Biosolid type A: used directly in agriculture; Biosolid type B: used for soil restoration; ND; not determined.

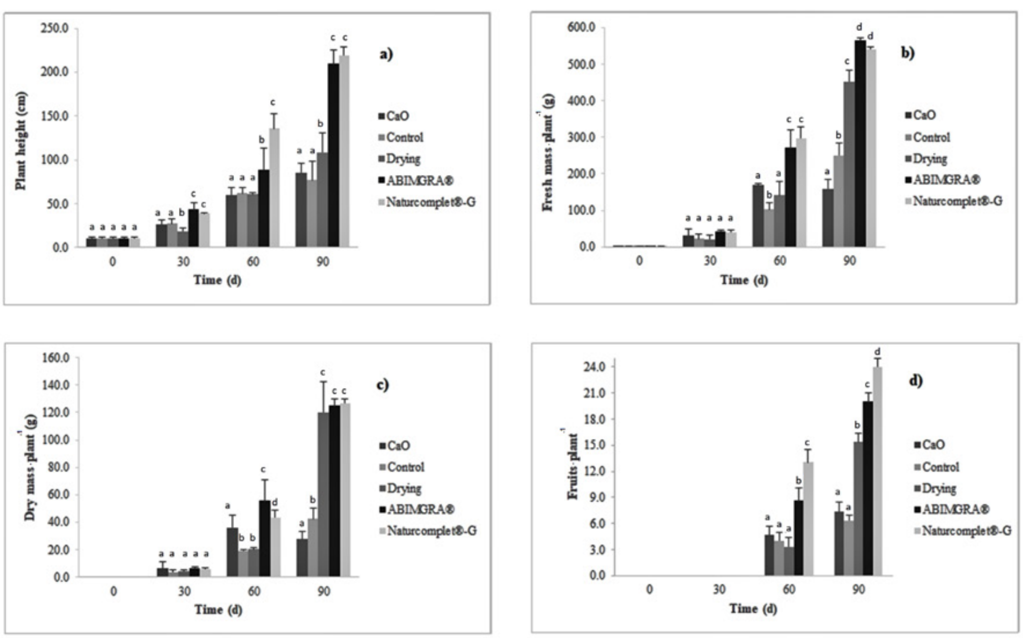

Figure 1. Plant height (a); fresh mass. plant^{-1} (b); dry mass. plant^{-1} (c); fruits. plant^{-1} (d) according to treatments: alkaline stabilization at 13% CaO, drying beds stabilization, control, ABIMGRA® and naturcomplet®-D fertilizer. Different letters indicate statistically significant differences with α = 0.05. Time: days after sowing.

not shown). The dehydrated biosolids showed higher absolute growth than the alkalinization treatment because these had a higher leaf area index and a higher light capture for their photosynthetic processes (Hernández *et al*., 2018). This same process was observed in plants such as the potato (Santos *et al*., 2017), and sorghum (Hernández *et al*., 2018).

The number of fruits was higher with dehydrated biosolids than with alkaline biosolids. However, traditional fertilizer obtained the highest number of fruits. ABIMGRA® and Naturcomplet®-G had a yield of 7.5 $kg.m^{-2}$ and 9 $kg.m^{-2}$ respectively, while tomato seedlings fertilized with dehydrated biosolids and alkaline biosolids had a yield of 5.73 $kg.m^{-2}$, and 2.74 $kg.m^{-2}$ respectively. These results are below traditional production, which has an average yield of 35 $kg.m^{-2}$ (Castellano, 2011). However, it must be considered that in this study, only the initial fertilization was carried out while in the traditional crop, fertilization every week was carried out (Bojacá *et al*., 2019).

Chemical and microbiological analysis of tomato fruits

Tomatoes produced with biosolids and traditional fertilizers presented slow levels of heavy metals (lead, arsenic and chromium). Trebolazabala *et al*. (2017), determined that the concentration of heavy metals in tomato fruits is lower than in other parts of the plant. It should be noted that the tomatoes obtained with alkaline biosolids presented a concentration of iron and zinc of 65 $mg.kg^{-1}$ and 21 $mg.kg^{-1}$ respectively, lower than the tomatoes obtained with dehydrated biosolids, ABIMGRA and Naturcomplet®-G. This agrees with what was described by Wang *et al*. (2000), who determined that some heavy metals are more available to plants in acid soils than in alkaline soils (table 2).

The results obtained in this study demonstrated the absence of pathogenic microorganisms in the tomatoes. The foregoing corroborates that both sewage sludge stabilization processes were effective in eliminating pathogenic microorganisms and that they can be safely used in agriculture as fertilizers (Table 2). The tomatoes did not present pathogenic microorganisms because the fruits had no contact with the soil, the irrigation water was potable, and sanitary-hygienic conditions of washing and disinfection were adequate. Besides, the stems and fruits did not suffer mechanical injuries in the field and after the harvest. Studies carried out with *Salmonella* sp., revealed its capacity to internalize, through the lacerated stems and flowers, to grow inside the plant, and to migrate to the fruit, surviving during the growth of the plants, the flowering, the development, and maturation of the fruits (Orozco *et al*., 2008).

Table 2. Chemical and microbiological parameters of tomatoes planted with biosolids, and traditional fertilizers.

Parameters	Dehydrated biosolid	Alkaline biosolid	ABIMGRA	Naturcomplet®-G	Control soil
Nitrogen (%)	2.38	2.10	2.60	2.60	2.60
Phosphorus (%)	0.40	0.40	0.40	0.40	0.40
Potassium (%)	3.20	3.20	3.60	3.60	3.60
Calcium (%)	0.24	0.20	0.28	0.28	0.28
Magnesium (%)	0.16	0.20	0.20	0.20	0.20
Sodium (%)	0.02	0.01	0.02	0.02	0.02
Sulfur (%)	0.02	0.20	0.17	0.17	0.17
Iron ($mg.kg^{-1}$)	81.1	65.3	73.0	73.1	72.8
Copper ($mg.kg^{-1}$)	6.20	5.74	6.0	6.0	5.80
Manganese $mg.kg^{-1}$)	5.44	4.69	4.34	4.34	4.34
Zinc ($mg.kg^{-1}$)	24.9	21.0	26.0	25.7	25.7
Boron ($mg.kg^{-1}$)	13.9	16.1	13.4	13.4	13.4
Arsenic ($mg.kg^{-1}$)	<0.3	<0.3	<0.3	<0.3	<0.3
Cadmium ($mg.kg^{-1}$)	0.45	0.47	0.80	0.80	0.80
Chrome ($mg.kg^{-1}$)	<1.5	<1.5	<1.5	<1.5	<1.5
Lead ($mg.kg^{-1}$)	<0.3	<0.3	<0.3	<0.3	<0.3
Coliforms (Log $CFU.g^{-1}$)	<3	<3	<3	<3	<3
Salmonella $sp.25g^{-1}$	A*	A*	A*	A*	A*
Helminths ($eggs.4g^{-1}$)	<1	<1	<1	<1	<1
Phages ($PFU.g^{-1}$)	<10	<10	<10	<10	<10

*Absence in 25 g of tomato

Conclusions

Compared to the alkaline biosolids, the dehydrated biosolids had a significant effect on the height, the fresh mass, the foliar area, and the number of fruits per plant. The dry mass of the plants fertilized with dehydrated biosolids and traditional fertilizers were similar. This way, the use of dehydrated biosolids positively influences the production of tomato plants without altering the food safety and constitutes an alternative to carry out adequate disposal of sewage sludge of Sotaquirá.

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