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Research paper

Waste from sewage treatment plants used in soybean cultivation: its influence on crop development

Resíduos de estação de tratamento de esgoto no cultivo de soja: influência no desenvolvimento da cultura

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ABSTRACT: The aim of the present study is to assess the effect of using composted sewage sludge (CSS) and wastewater from a sewage treatment plant (WW) on soybean plants' development. Treatments were assessed through completely randomized design experiments carried out at split-plot arrangements based on nitrogen fertilization levels and types and on irrigation water nature – potable (WP) and wastewater (WW). Seven nitrogen fertilization levels were distributed into two plots represented by irrigation with WP and WW, namely: T0 = without nitrogen fertilization; T1 = 100% chemical nitrogen fertilization; T2 = 50% chemical nitrogen fertilization + 50% nitrogen fertilization via CSS; T3, T4, T5 and T6 corresponded to 100%, 150%, 200% and 250% CSS nitrogen fertilization, respectively. Conventional nitrogen fertilization replacement by CSS did not significantly change the behavior of the assessed variables: plant height and mass of 100 grains. This finding points towards the possibility of saving inputs by replacing chemical fertilization by organic fertilization. Irrigation with wastewater led to 37% increase in dry matter mass and 21% in mass of 100 grains.

Keywords: Wastewater; Organic compost; Irrigation; Reuse.

RESUMO: *Objetivou-se avaliar o efeito da utilização de lodo de esgoto compostado (LEC) e de efluente de esgoto tratado no desenvolvimento de plantas de soja. Os tratamentos foram avaliados a partir do delineamento inteiramente casualizado em arranjo de parcelas subdivididas e variaram em função de níveis e tipos de adubação nitrogenada e da natureza da água de irrigação – potável (AP) e efluente de esgoto tratado (EET). Os sete níveis de adubação nitrogenada foram distribuídos nas duas parcelas, representadas pela irrigação com AP e EET, sendo assim designados: T0 = sem adubação nitrogenada; T1 = 100% de adubação nitrogenada química; T2 = 50% de adubação nitrogenada química + 50% adubação nitrogenada via LEC; T3, T4, T5 e T6 corresponderam à 100, 150, 200 e 250% da adubação nitrogenada proveniente do LEC, respectivamente. A substituição da adubação nitrogenada convencional pelo LEC não alterou significativamente o comportamento das variáveis: altura de planta e massa de 100 grãos, indicando a possibilidade de economia de insumos por meio da substituição da adubação química pela adubação orgânica. A irrigação com EET promoveu incrementos de 37% na massa de matéria seca e 21% na massa de 100 grãos.*

Palavras-chave: *Água residuária; Composto orgânico; Irrigação; Reuso.*

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INTRODUCTION

The proper disposal of sewage treatment plant (STPs) waste is necessary to minimize environmental impact and to promote public health. Sewage sludge and wastewater stand out among waste generated in these plants, which have great potential to be used in agriculture, since they are rich in macro and micronutrients - essential elements for plants' full development.

Waste agricultural use can be featured as environmentally sustainable destination for sewage sludge, as it promotes nutrients' recycling and benefits plants' cultivation, and soil physical-chemical and biological features. It is a globally consolidated alternative only used in few Brazilian states (BITTENCOURT *et al.,* 2017).

Many studies have pointed out the benefits of using sewage sludge and wastewater in agricultural crops, since these elements have positive effect on the development and production of different crops, such as oat, wheat, triticale, sunflower, maize, beans and soybeans (LOBO, 2010; LACERDA *et al.,* 2011; FREITAS *et al.,* 2012; LOBO *et al.,* 2013; FEITOSA *et al.,* 2015; GOMES, 2016; SILVA, 2022).

Sewage sludge is rich in organic matter and nutrients, mainly nitrogen (N), therefore, it has the potential to be used in some crops, including soybeans. According to Lobo *et al.* (2012), sewage sludge is 18% more efficient than chemical fertilizer as source of nutrients for soybean growing on average. In addition, waste can boost nodules' formation in the roots of soybean plants (VIEIRA; TANAKA; SILVA, 2004) and increase biological N fixation rates in this crop (CURRIE, ANGLE; HILL, 2003), a factor that favors plant development and yield. Soybean (Glycine max (L.) Merrill) is one of the most important crops in the economic world, besides being the most cultivated oilseed in the world (COSTA NETO; ROSSI, 2000). Its growth in Brazil is associated with technological and scientific advances in the production sector, rather than just with the expansion of agricultural-potential land. These technologies regard pest and disease management or, most of all, soil management, fertilization, and liming (FREITAS, 2011).

According to Embrapa (2021), Brazil has surpassed the United States in soybean production. Soybeans have been considered the grain of the century, given the growth in cultivated area and grain production, due to their versatile use in human food, animal feed and biofuel production. Soybean grain yield depends on the cultivar's genetic potential and on factors, such as region, climate, soil, water and nutrient availability, which can impair photosynthesis and, consequently, crop yield (KUSS *et al.,* 2006).The literature on soybean management is extensive (EMBRAPA, 1994; FARIAS; NEPOMUCENO; NEUMAIER, 2007; EMBRAPA, 2013), but there is little information on this plant species grown under organic nitrogen fertilization. According to Taiz and Zieger (2004), N is absorbed as N^2 and transformed into NH_4, in legume crops, through symbiotic processes with bacteria. There are reports about the use of sewage sludge as fertilizer to boost or inhibit the nodulation process, although promoting high yield.

According to Lobo *et al*. (2012), sewage sludge is 18% more efficient than chemical fertilizer as nutrients source for soybean cultivation, on average.

Behling *et al.* (2009) assessed a soybean crop and concluded that using sludge at increasing doses to replace mineral fertilization increased grain yield by 1,224 kg. ha^{-1} and improved the land productive potential. They also reported that high mineral N supply to soybean plants can lead to high soil N absorption. This process reduces biological nitrogen fixation, because plants reduce fixation in nodules under high N availability conditions. However, Lobo *et al.* (2012) observed increase in the number of nodules due

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to increased sewage sludge application in the soil (up to of 20 $t.ha^{-1}$), although this number decreases from this value onwards.

Given the relevance of studies on the effects of nitrogen-rich organic waste application in legume crops, the aim of the current study was to assess the effect of using composted sewage sludge and sewage treatment plant wastewater on soybeans (*Glycine max* L.) development.

MATERIAL AND METHODS

The study was carried out in pots (43L), in non-acclimatized greenhouse, at the Department of Soils and Environmental Resources of the Agronomic Sciences School - FCA/UNESP, Botucatu-SP.

The collected soil was classified as Dystrophic RED LATOSOL, with medium texture (SANTOS *et al*., 2013). It was prepared with P_2O_5 and K_2O complementary chemical fertilizations to meet soil nutrient requirements needs in terms of P and K, according to the recommendations proposed by Cantarella *et al.* (2022). The Monsoy 7211 RR cultivar was used, with 8 seeds per pot, leaving 3 plants after thinning.

Treatments were assessed through completely randomized design experiment, subdivided in plots based on nitrogen fertilization levels and types and on irrigation water nature - potable water (PA) and treated sewage waste (TSW), with 10 replicates per treatment.

Nitrogen fertilization required for full crop development (100% of plant demand) was based on the study by Lobo *et al.* (2012). It resulted in recommendation of 66 kg ha-1 N. The seven nitrogen fertilization levels were distributed into two plots represented by irrigation with AP and EET, namely: T0 = no nitrogen fertilization; T1 = 100% chemical nitrogen fertilization; T2 = 50% chemical nitrogen fertilization + 50% nitrogen fertilization via composted sewage sludge (CSS); T3, T4, T5 and T6 corresponded to 100%, 150%, 200% and 250% CSS nitrogen fertilization, respectively. Nitrogen (N) in waste was considered (1.10%, **Table 1**) at 30% mineralization to calculate sludge dose.

Table 1. Chemical characterization of composted sewage sludge.

N (%)	P_2O_5 (%)	MO (%)	C/N	pH
1.10	1.28	20.16	10/1	6.2

Treated sewage waste (TSW) was provided by Botucatu-SP sewage treatment plant outlet, whereas drinking water was collected from the municipal public supply network. TSW samples were collected to feature pH, electrical conductivity, nitrogen, and phosphorus during the experimental time (11 weeks). Samples were preserved according to APHA (2005) and their physicochemical parameters were determined according to the methodology adapted from Malavolta et. al (1997). TSW featuring results are shown in **Table 2**.

Localized irrigation based on self-compensating drippers was used for water distribution to replenish the crop's evapotranspiration and to keep the pots at 70% field capacity.

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Table 2. Results of the physical-chemical characterization of the treated sewage effluent.

	pH	EC ($mS.cm^{-1}$)	N ($mg.L^{-1}$)	P ($mg.L^{-1}$)
Average	7.7	0.4	18.1	3.8

The crop analysis included measuring plant height (cm) and determining dry matter mass (DM) at 60 days after emergence (DAE) (g. $plant^{-1}$), as well as assessing the mass of 100 grains (g) at the end of the production cycle, and collecting grains at 97 DAE.

All the results were subjected to analysis of variance and to 5% Tukey mean comparison test. Regression analysis was used, if significance reached 5%, for treatments only based on sewage sludge using (T3, T4, T5 and T6).

RESULTS AND DISCUSSION

CSS and TSW had significant impact on soybean growth due to significant interaction between the two factors set for the plant height variable- the highest average was recorded for T0 irrigated with TSW (**Table 3**). With respect to control treatments (T0), TSW led to 23% increase in plant height in comparison to the PA-irrigated plot.

Table 3. Average results for soybean plant height, dry matter mass and 100-grain mass.

Type of Water	Treatments							
	T0	T1	T2	T3	T4	T5	T6	Average
				Plant height 60 DAE (cm)				
DW	81.0^{Ba}	91.1^{Aab}	73.2^{Aabc}	69.1^{Abcd}	67.6^{Acd}	64.3^{Ad}	62.7^{Ad}	-
WW	100.0^{Aa}	75.1^{Bb}	79.8^{Ab}	72.2^{Ab}	66.6^{Ab}	68.4^{Ab}	64.7^{Ab}	-
				CV1(%) = 16.1; CV2(%) = 12.5; MSD1 = 9.6; MSD2 = 13.0				
				Dry matter mass 60 DAE ($g.plant^{-1}$)				
DW	-	-	-	-	-	-	-	12.1^{B}
WW	-	-	-	-	-	-	-	16.6^{a}
				CV1(%) = 17.4; MSD3 = 0.9				
				Mass of 100 grains (g)				
DW	-	-	-	-	-	-	-	15.2^{B}
WW	-	-	-	-	-	-	-	18.6^{a}
Average	13.6^{b}	17.3^{a}	17.3^{a}	17.3^{a}	16.7^{a}	17.1^{a}	19.0^{a}	
				CV1(%) = 7.9; CV2(%) =13.0; MSD3 = 0.5; MSD4 = 2.4				

T0: no nitrogen fertilization; T1: 100% chemical nitrogen fertilization; T2: 50% chemical nitrogen fertilization + 50% nitrogen fertilization via composted sewage sludge - LEC; T3, T4, T5 and T6: 100, 150, 200 and 250% of nitrogen fertilization via LEC, respectively. DW: drinking water; WW: wastewater; CV1: coefficient of variation of the plot; CV2: coefficient of variation of the sub-plot; MSD1: minimum significant difference of the plot within the sub-plot; MSD2: minimum significant difference of the sub-plot within the plot; MSD3: minimum significant difference of the plot; MSD4: minimum significant difference of the sub-plot. Averages followed by the same letter, upper case in the column and lower case in the row, do not differ by the Tukey test at 5% probability.

Freitas *et al.* (2012) assessed the effects of using treated domestic sewage and well water on sunflower plants and observed higher plant height averages after reuse water application. Alves *et al*. (2018) found no difference in growth in the maize crop growth between the control treatment (clean water) and treatments with treated sewage waste (TSW). On the other hand, Gomes (2016) assessed the effect of TSW irrigation on soybean grown in pots and found no difference in mean plant height at 55 and 75 DAE,

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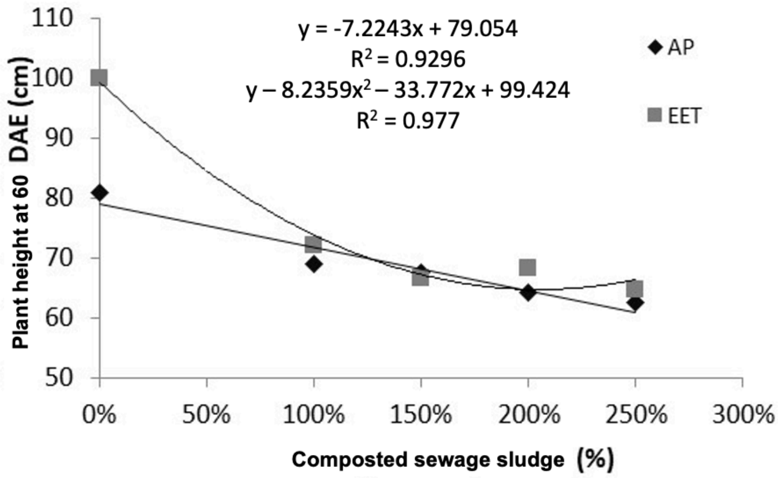
between treatments with TSW and PA. However, there was significant difference at 95 DAE, when TSW increased plant height by approximately 48% in comparison to PA-irrigation.

The comparison of treatments with the same amount of N (T1, T2 and T3) showed that PA irrigation led to the best height result in T1 (100% chemical nitrogen fertilization), which did not statistically differ from T2 (half chemical + half organic). On the other hand, the plot irrigated with TSW presented no statistical difference between mean plant height in these treatments (T1, T2 and T3). This finding points out the likely replacement of chemical fertilization by organic fertilization, without damaging crop development. However, increased CSS doses in the soil limited soybean growth (**Figure 1).**

Figure 1. Plant height at 60 days after emergence, as a function of the application of 0, 100, 150, 200 and 250% composted sewage sludge, equivalent to 0, 66, 99, 132 and 165 kg.ha^{-1} of N.



There was no significant interaction between plot and subplot when it comes to dry matter mass and 100-grain mass (M100). This finding points out that only water types and/or fertilizer levels had influence on these variables (**Table 3**). Thus, TSW increased MMS by 37% and M100 by 21% in comparison to PA irrigation.

Divergent results were found by Melo *et al.* (2020), who assessed WWTP wastewater as bean-irrigation alternative. They observed lower mean plant height and MMS by using wastewater. On the other hand, Lacerda *et al.* (2011) found significant height and dry phytomass increase in pigeonpea plants (*Canavalia ensiformis*) irrigated with wastewater from a domestic sewage treatment stabilization lagoon, in comparison to plants irrigated with tap water. Feitosa *et al.* (2015) observed significant effects on the dry mass of cowpea leaves irrigated with wastewater. They found the best results in comparison to irrigation with well water. Gomes (2016) also recorded increase by more than 100% in MMS in soybean plants irrigated with wastewater from WWTP in comparison to PA irrigation.

Freitas *et al.* (2012) and Lacerda *et al.* (2011) suggest that nutrients found in wastewater may account for some crops best vegetative performance, as herein observed through variables plant height (T0), MMS and M100 (**Table 3**).

Only T0 significantly differed from the other treatments (**Table 3**) in the M100 variable in comparison to the other treatments: the lowest mean and no difference between CSS treatments. However, only treatments with sewage sludge and the control

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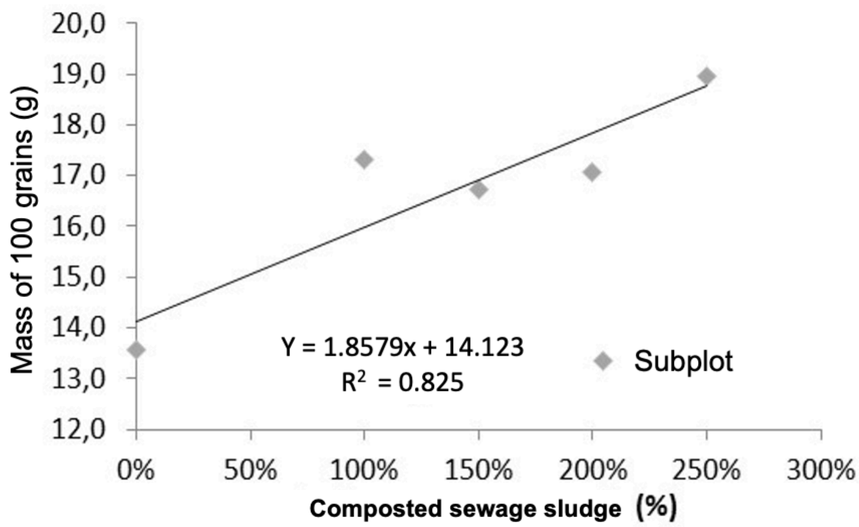
(T0) showed significant difference (p-value<0.05) in the subplot when the analysis of variance was carried out for regression test (**Figure 2**).

Figure 2. Mass of 100 grains as function of applying 0%, 100%, 150%, 200% and 250% composted sewage sludge, which is equivalent to 0, 66, 99, 132 and 165 kg.ha^{-1} N, respectively.



It was possible observing that sewage sludge had positive effect on M100, regardless of used irrigation water. Increase in soil organic compost raised the means recorded for this variable. The analysis of variance for regression test was not significant for MMS (p-value > 0.05).

Gomes (2022) found that using biosolids reduced the mean M100 of bean plants. Lobo *et al*. (2013) concluded that increased doses of sludge in the soil led to increased triticale grain yield and it did not influence dry matter yield and 1000-grain mass. Silva (2022) assessed the effects of increased doses of sewage sludge compost in the soil on soybeans and they found that organic waste application increased mean M100 and plant height. This finding corroborates results in the current study.

CONCLUSION

Replacing chemical nitrogen fertilization by composted sewage sludge (CSS) did not significantly change the behavior of the following variables: plant height and 100-grain mass. This finding points towards the possibility of saving inputs by replacing chemical fertilization by organic fertilization.

Increased CSS doses in the soil impaired soybean plants' growth and did not significantly influence dry matter mass behavior, but it had positive effect on the mass of 100 grains.

Irrigation with treated sewage waste (TSW) increased by 37% the dry matter mass and by 21% the mass of 100grains.

Using TSW increased mean plant height in treatments without complementary nitrogen fertilization (chemical or organic in the soil).

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