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Effects of the application of treated domestic sewage via surface and subsurface drip irrigation on the solution and chemical properties of the soil in an orange plantation

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The use of treated domestic sewage (TDS) in agriculture by drip irrigation in the soil subsurface can serve as an extra treatment and also provide higher availability of water and nutrients to plant roots. It represents safer and healthier cultivation for crops, producers and consumers, and allows the direction of better quality water for domestic consumption. This study aimed to analyze the possible effects of TDS irrigation on chemical and biological properties of the soil in an orange plantation. The experiment was conducted on Lagoa Bonita Farm, at the Adventist University Center of São Paulo - UNASP - Engenheiro Coelho Campus, SP. A block design with three replications was used in the following treatments: soil irrigated with TDS on the surface, soil irrigated with TDS in the subsurface, and soil with no irrigation. Soil samples were collected for chemical and biological analyzes, as well as samples of the treated domestic sewage used. The TDS characteristics were within the parameters allowed by law. Considering the chemical parameters and the types of irrigation analyzed, the highest results observed were: K: 11 mmolc.dm^3, Ca: 30 mmolc.dm^3, Mg: 7 mmolc.dm^3, and pH: 5.5.

Key words: Reuse, citrus, soil chemistry, soil solution.

INTRODUCTION

The rational use of soil and water is currently seen as vital to the existence and livelihood of future generations around the world. Brazil has the largest availability of arable land and water in the planet, however, new ways of producing food and utilizing sustainable alternatives must be studied due to the rapid reduction and scarcity of land and water throughout the planet (Scolari, 2005).

Treated domestic sewage (TDS) collected from

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stabilization ponds for use in agricultural irrigation is an alternative water source, as it provides essential nutrients to the crops and may partially or fully replace commercial chemical fertilizers. The application of TDS in the soil subsurface, despite having higher costs and risks of clogging, represents economic benefits due to the better use of water and nutrients by plant roots, less evaporation and improved plant health by avoiding surface runoff (Souza et al., 2012).

Subsurface drip irrigation with wastewater may maximize land use, allowing the reduction of production costs and the intensive use of machines with expertise and implementation of manpower, besides reducing seasonality, providing more favorable prices for producers and consumers, incorporating new areas, facilitating the establishment of agricultural industries, improving the quality and standardization of products, allowing the opening of new markets, producing noble crops, minimizing climate risks, among others (Andrade Neto, 1997).

The application of treated domestic sewage via subsurface drip irrigation tends to be a relevant form of irrigation due to the characteristics of the system, which disposes water directly in the root system and thus presents a high uniformity of application, avoiding wetness of the soil surface and plant shoots. It also eliminates drift issues, increasing the efficiency of fertilizer application. Even though several studies have been conducted on the use of treated domestic sewage via subsurface irrigation in agriculture, the application of this technique by farmers is still limited.

The reduction or minimization of environmental impacts in agriculture is essential for the adoption of models that measure the quality of the environment considering the various factors that promote environmental sustainability, such as product quality and production indicators, consumption and pollution of water resources, soil quality indicators and flow of gases with a global warming potential.

The advantage of using treated domestic sewage is to allow better conservation of water bodies and contribute with considerable amounts of nutrients to the soil, resulting in improved fertility and reduced costs with mineral fertilizer (Souza et al., 2012). With the expansion of sewerage networks, public awareness, and the monitoring and inspection by environmental agencies, the disposal of treated domestic sewage by soil subsurface irrigation in agriculture will certainly be adopted (Oliveira et al., 2013).

Throughout the last years, several studies have shown concern about the application of wastewater to the soil. The operation and maintenance of the systems must be constant in irrigation with post-treated sewage, as the water used has characteristics that may modify and destroy soil fertility if no proper precautions are taken (Lima et al., 2006). However, the soil is a natural filter. It is a combination of physical and chemical treatments and biological processes occurring in the soil-plant-atmosphere system, but the clearance rate of said system is slow. Despite providing nutrients to the plants, wastewater is also a source of contaminants to the soil, in addition to causing nitrate leaching into groundwater and emissions of greenhouse gases (Tzanakakis et al., 2007).

This study aimed to assess chemical behavior parameters in soil irrigated with treated domestic sewage applied via subsurface drip irrigation in an orange plantation in the city of Engenheiro Coelho, São Paulo.

MATERIALS AND METHODS

The experiment was installed in 2015, in the city of Engenheiro Coelho - SP (22° 29' 18" S, 47° 12' 54" W), on Lagoa Bonita Farm, in an orange plantation owned by the Brazilian Central Union of the Seventh-day Adventist Church, located at UNASP, next to a sewage treatment plant. The plots measured 6 m x 50 m, totaling an area of 300 m^2 per experimental plot. The study was conducted between August 2015 and January 2016.

According to the Köppen classification, the local climate is humid subtropical, with temperatures above 22°C in the hottest month of the year and below 18°C in the coldest month. Annual rainfall in the region is 1,328 mm and the predominant soil is classified as typical eutrophic Red Yellow Argisol.

The wastewater used was collected from a secondary facultative pond at UNASP's sewage treatment plant (STP) by a pressurized sand filter system to remove suspended solids. The STP consists of Australian-type stabilization ponds, with a receptive anaerobic pond and two facultative ponds (one primary and the other secondary).

The application of treated domestic sewage was performed by a surface irrigation system and by a subsurface irrigation system at 0.2 m deep from the soil surface. The drippers used (Super Typhoon, by Netafim) were spaced every 0.5 m, with a flow rate of 1.75 L h^{-1} and a wall thickness of 0.38 mm.

Irrigation was performed every day from Monday to Friday during the months of August to December, 2015, based on the following treatments: Drip Irrigation (DI), Subsurface Drip Irrigation (SDI) and no irrigation (NI). Data concerning to evapotranspiration were estimated by the Hargreaves-Samani method, based on temperature data from a weather station installed next to the experimental area.

Treated domestic sewage samples were collected for the verification of the following parameters: pH, Fe, EC (in dS m^{-1}), Calcium, Iron, Total Phosphorus, Nitrate, oils and grease, COD and Sulfide. The pH was determined by the hydrogen- ion activity of the soil-water solution by means of potentiometry. The exchangeable acidity (Al^{+3}) was extracted with potassium chloride (KCl) 1 mol L^{-1} and quantified by titration with sodium hydroxide (NaOH) at 0.025 mol L^{-1} (Embrapa, 1999). Phosphorus (P) was extracted with Melich solution and determined by calorimetry and flame photometry. The calcium ion (Ca^{2+}) was extracted with KCl at 1 mol L^{-1} and quantified by inductively coupled plasma optical emission spectrometry (ICP-OES).

Transversely to the crop row, a trench was opened (0.2 m wide and 0.4 m deep), using as a reference the center of the planting furrow for collecting soil samples for physical and chemical characterization. Three simple soil samples were collected per depth (0.20 m and 0.20-0.40 m) in the direction parallel to the surface. The following soil parameters were assessed: Organic Matter (OM), pH, P, K, Ca, Mg, H^+Al, Al, SB, CEC, S, Cu, Fe, Mn, Zn and B.

Samples of soil solution were collected by extractors installed in

Table 1. Mean values of the main physicochemical parameters of the TDS.

Parameter	Legal standards (Conama-430/2011)	Mean values	SD
pH	5 to 9	7.22	0.05
EC ($dS.m^{-1}$)	1.0 to 3.1	0.83	38.11
Ca (mgL^{-1})	20 to 100	23.3	12.26
Iron (mg $L^{-1)}$	15.0	0.34	0.21
Total Phosphorus (mg L^{-1} P)	0.025	8.40	3.15
Nitrate (mg L^{-1})	10.0	0.14	0.09
Oils and grease (mg L^{-1})	30	45	17.44
COD (mg L^{-1})	360	35	14.10
Sulfide (mg L^{-1})	0.002	0.71	0.27

Source: Biosciences laboratory – UNESP – Botucatu/SP.

the treatment units for the analysis of the following parameters: N, P, K, Ca, Mg, S, B, Cu, Fe, Zn, Mn, pH and EC.

The experiment consisted of a randomized block design with three replications and five treatments, totaling 20 experimental units. The treatments were based on the employment of treated domestic sewage, which was applied through different blades for total irrigation of the subsurface and surface according to the atmospheric demand, and on the Hargreaves-Samani method, which adapts to dry periods.

Data were subjected to analysis of variance and mean values were compared by Tukey's test at 5% probability using the computer system SISVAR version 5.1 Build 72 (Ferreira, 2011).

RESULTS AND DISCUSSION

Table 1 shows the results of the TDS samples collected from UNASP's Sewage Treatment Plant during October, November and December as well as the legal standards regarding effluent disposal established by Resolution 430, from May 13, 2011, by the National Environmental Council – CONAMA.

Most mean values of the parameters of the TDS employed in the irrigation during the experiment are in accordance with the Brazilian legal standards. The pH was slightly basic. Ayres and Westcot (1991) recommend pH between 6.5 and 8.4 for water used in irrigation.

The concentration of H+ and OH- in irrigation water may exert influence on the availabilty and absorption of nutrients by plants, on soil structure and properties, and also on irrigation systems. Some parameters showed values above the standard set by the Brazilian regulation for the use of effluents in irrigation, such as phosphorus, with a value of 8.40 mg L^{-1}, whereas 0.025 mg L^{-1} is permitted; sulfide, with a value of 0.27 mg L^{-1}, whereas 0.002 mg L is permitted; and oils and grease, with a value of 45 mg L^{-1}, whereas 30 mg L^{-1} is permitted.

The use of treated domestic sewage in irrigation depends on the correct management of the irrigation system and on the monitoring of the charecteristics of the soil and crop, since the effects of salinity, sodicity and alkalinity hinder the continuous usage of wastewater in the irrigation of agricultural crops in general.

Total coliform content was 460 per ml of water and thermotolerant coliform content was 43 per ml of water. According to CONAMA Resolution 20/86, the limit is up to 5,000 total coliforms per 100 ml (CONAMA, 1986).

Rainfall during the period of the experiment was 832.9 mm. Figure 1 shows climatological and evapotranspiration data.

Table 2 shows the results of the soil analysis before irrigation with TDS and of the analysis of variance of the different treatments applied.

Based on the results of the analysis of the organic matter found in the soil after the application of TDS, the subsurface drip irrigation caused a significant positive effect. As shown in Table 2, the organic matter content in the soil after the application of treated domestic sewage via SDI was higher than the content in the initial, DI and NI treatments. Most likely, the higher nitrogen and carbon concentration in the other treatments favored the quick mineralization and decrease in the organic matter content of the soil. Feigin et al. (1991) state that the typical C:N ratio of secondary domestic sewage is near five or lower, which causes these elements to easily decompose in the soil and be assimilated by plants.

The pH was also higher in the application of treated domestic sewage via SDI. Higher pH is related to effluent alkalinity, addition of exchangeable cations and anions to soil, and changes in the N cycling production of OH- ions due to enhanced denitrification or nitrate reduction. Fonseca (2005), in a study on irrigation with treated sewage effluent, obtained low soil alkalinization during the experiment regardless of the irrigation system employed.

The values of H + Al of the applications presented variation when compared to the values of the initial chemical analysis. Application via DI presented the highest value, 52 $mmolc.dm^3$. Moreover, the soil that received TDS via SDI presented the lowest values of potential acidity, contrasting with its high organic matter value - that should have contributed for an increase in the potential acidity - and serves as evidence of the inversely proportional relationship between organic matter and pH.

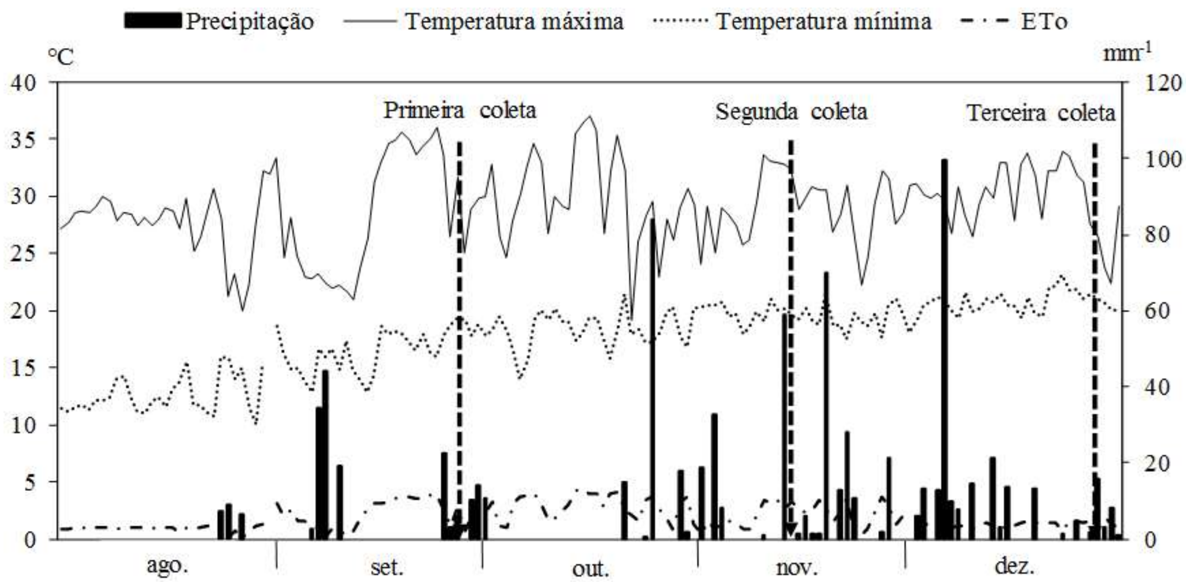

Figure 1. Climatological data during the experiment.

With respect to K, the mean values found were lower in both DI and SDI in comparison with the initial treatment and non-irrigated areas. Silva and Borges (2008) found similar results in a study of an orange crop under successive irrigation with treated domestic sewage. Irrigation with waste water allows an increase in sodium concentration, which consequently benefits the displacement of K in the soil exchange complex. In some cases, there might be a decrease in K due to its leaching and plant absorption.

The highest value of P was found in the application of treated domestic sewage via DI. In relation to Ca, the lowest values were found in the superficial layers of the soil, which might be associated to the migration of Ca^+ from the soil to the solution in the exchange complex, as there is more nutrient absorption by plants, mainly citrus. Carbonate accumulation, especially calcium carbonate, caused by prolongated irrigation can promote soil cementation, thus hindering the penetration of irrigation water and roots (Egreja Filho et al., 1999; Rego Filho, 2014).

A directly proportional relationship between the decrease of pH and Mg values was observed in the treatments, suggesting a correlation between Mg and soil acidity.

Medeiros et al. (2005) studied a coffee crop under irrigation with TDS and reported that the factors that represent the main negative impacts for the soil in this type of management were the increase in the exchangeable sodium concentration and in the electrical conductivity (EC), the sodium adsorption ratio (SAR) and the exchangeable sodium percentage (ESP).

Table 3 depicts the mean values of the chemical properties of the soil solution after irrigation with treated domestic sewage.

The pH values of the soil solution were higher than the pH values of the soil. Interestingly, under SDI, the pH of the soil solution was the lowest, whereas the pH of the soil was the highest. The pH is an extraordinary indicator of the soil chemical conditions as it has the capacity to interfere directly or indirectly in the way other chemical elements are disposed and interact in the soil.

Electrical conductivity was higher in the application of the TDS via SDI. The precipitation that occurred during the experiment might have influenced the dissolution of effluent salts, causing the decrease in the EC of the soil solution. As the dispersion in the subsurface layers takes more time, the highest electrical conductivity values were found in this type of application.

The highest concentration of K was found in the treatment via SDI, possibly due to its absorption by plants and leaching. Authors such as Silva and Borges (2008) and Leal (2007) state that K concentration in the soil is variable and might be associated to the dynamics of K in the soil-plant-effluent system.

Similarly, the highest concentration of Ca was found in the same type of application, what evidences that the dynamics of this element was influenced by its absorption by plants and leaching.

Magnesium dynamics were similar to the dynamics of Ca. Both presented higher concentration in the application via SDI.

In general, treated domestic sewage applied via SDI presented the highest concentrations in most of the parameters analyzed.

Azevedo and Oliveira (2005), in a study on a cucumber crop (*Cucumis sativus* L.) under irrigation with treated sewage effluent, did not report significant difference between phosphorus concentrations in the soil water regarding different types of applications. Statistically

Table 2. Analysis of variance of the soil chemical parameters.

Soil samples	OM (g.dm^3)	pH	P (mg.dm^3)	K	Ca	Mg	H + Al	S.B.	CEC (mmolc.d^3)	V%	S	Cu	Fe	Mn	Zn	B
				mmolc.dm^3							mg.dm^3					
Initial	19	4.2	38	1.6	12	5	41	18	59	30	-	13.5	56	2.0	4.2	0.39
DI	23	4.8	61	0.9	17	6	52	24	76	31	11	20.7	46	8.6	5.7	0.48
SDI	30	5.3	48	1.1	30	7	36	39	74	52	16	22.6	44	2.8	10.4	0.56
NI	18	4.7	34	1.7	15	4	43	21	64	33	29	12.9	57	1.8	5.5	0.57

DI- Drip irrigation; SDI – subsurface drip irrigation; NI – no irrigation.

Table 3. Mean values of the chemical properties of the soil solution under different treatments.

Treatment	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	pH	E.C (mS)
	mg.L^{-1}												
DI	55	0.9	18	23	10	10	0.07	0.04	0.06	0.14	2.6	6.54	0.607
SDI	62	1.5	29	43	11	13	0.1	0.35	0.08	0.41	2.1	6.21	0.769
NI	52	0.8	20	24	10	11	0.1	0.02	0.09	0.15	2.4	6.45	0.602

Source: Soil Fertility Laboratory– FCA UNESP – Botucatu/SP.

higher values of potassium, calcium and magnesium content were observed in the soil irrigated with TDS, as a possible result of the accumulation of these nutrients in the retained soil water.

Conclusion

The application of treated domestic sewage via subsurface drip irrigation provided an increase in the organic matter concentration of the soil in the orange plantation as well as in its nutrients, such as potassium, calcium and magnesium, leading to better plant development and productivity. However, research for a longer period of time in order to thoroughly assess the behavior of the nutrients applied to the soil and their relationship with orange productivity is recommended.

Conflict of Interests

The authors have not declared any conflict of interests.

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