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CARACTERIZAÇÃO FÍSICO-HÍDRICA DO SOLO APÓS CULTIVOS FERTIRRIGADOS COM ÁGUA RESIDUÁRIA TRATADA*

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1 RESUMO

Elevadas cargas de esgoto são destinadas aos corpos d'água no Brasil, podendo essa realidade ser mudada com o emprego de tecnologias para o uso agrícola desse resíduo. Assim, objetivou-se quantificar as mudanças no movimento e retenção de água em Latossolo Vermelho Eutrófico, após cultivo sequencial com a aplicação de água residuária sanitária tratada (ART). Para isso, foram utilizados cinco tratamentos (0= água limpa e adubação mineral; 50%; 100%; 150% e 200% da dose de ART limitada pelo elemento referência K^+ nos 3 primeiros cultivos e; 0= água limpa e adubação mineral; 100%; 200%; 300% e 400% da dose de ART limitada pelo elemento referência Na^+ no abacaxizeiro), no delineamento em blocos casualizados, com quatro repetições. Observou-se uma diminuição linear de 0,0972 mm h^{-1}, 0,0997 mm h^{-1} e 0,0073 cm h^{-1} na taxa de infiltração básica, no tempo de 1,5 h e na condutividade hidráulica, respectivamente, para cada mm de efluente adicionado no solo, além de aumentar a porcentagem de sódio trocável nas profundidades avaliadas. No entanto, tais alterações não ultrapassam os limites considerados seguros pela literatura.

Palavras-chave: infiltração; retenção de água; fertirrigação; esgoto sanitário.

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PHYSICAL-HYDRICAL CHARACTERIZATION OF THE SOIL AFTER FERTIRRIGATED CROPS WITH TREATED SANITARY WATER

2 ABSTRACT

High sewage loads are still released into water sources in Brazil. This can be changed using technologies that contributes for the use of part of this wastewater in agriculture. This study aimed to evaluate possible changes in the movement and water retention in Eutrophic Red Latosol, after sequential cultivation with the application of treated sanitary wastewater (ART). Five treatments were used (0: clean water and mineral fertilization, 50%, 100%, 150% and 200% of the ART dose limited by the reference element K^+ in the first 3 cultivation and 0: clean water and mineral fertilization, 100%, 200%, 300% and 400% of the ART dose, limited by the reference element Na^+ in pineapple crops, in a randomized block design with four replications. A linear decrease of 0.0972 mm h^{-1}, 0.0997 mm h^{-1} and 0.0073 cm h^{-1}, respectively, was

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observed in the basic infiltration rate, in the time of 1.5 h, and hydraulic conductivity, for each mm effluent increased in the soil; in addition, in the percentage of exchangeable sodium at depths evaluated. However, such changes do not exceed the limits considered safe by the literature.

Keywords: infiltration; water retention; fertigation; sanitary sewage; water reuse.

3 INTRODUCTION

The reduction in rainfall observed in Brazil in recent years, especially in semiarid regions, is an alarming process and requires investment in technologies and studies for the efficient use of high-quality water as well as other sources not used for human consumption.

The direct discharge of sewage into water bodies contributes to a reduction in water quality and is still common in many cities in the country (NATIONAL WATER AGENCY , 2017) . Even after treatment and following current legislation (BRAZIL, 2005; MINAS GERAIS, 2008), the effluents from treatment systems still contain elements capable of eutrophicating the receiving bodies.

One of the possible destinations for treated sanitary wastewater (ART) is agriculture (ALVES NETO et al., 2016; ALVES et al., 2018; SANTOS et al., 2016; SILVA, 2018) . This possibility helps conserve the availability of high-quality water and promotes the natural recycling of nutrients (LIBUTTI et al. , 2018) .

However, caution is needed when using ART as a source of nutrients for plants since successive applications can compromise soil quality (SANTOS et al. , 2017) , such as by promoting changes in infiltration and water movement in the soil due to the risk of clay dispersion (MATOS; MATOS, 2017; MATOS; MARTINS; LO MONACO, 2014) . Compared with Ca2+ and Mg2+, high concentrations of Na+ in the soil can cause deterioration of the soil structure by dispersing colloids and subsequently clogging macropores, causing a decrease in permeability to water and gases (HOMEM et al., 2014). Knowledge of the physical/chemical characteristics of the soil is of paramount importance for the conscious and safe management of ART. Several studies highlight the importance of this topic (CARVALHO et al. , 2014; NASCIMENTO; FIDELES FILHO, 2015; SANTOS et al. , 2016; SILVA, 2018) .

Therefore, the objective of this study was to evaluate the changes in water movement and retention in Eutrophic Red Latosol after sequential cultivation with the application of treated sanitary wastewater (ART).

4 MATERIAL AND METHODS

The experiment was conducted from January to March 2018 in the experimental area of the Minas Gerais Sanitation Company (Copasa)/Unimontes, located next to the Janaúba - MG Sewage Treatment Plant (ETE), whose geographic coordinates correspond to 15° 46' 14.5” S latitude and 43° 19' 14.31” W longitude, with an altitude of 534 m. The climate is classified as Aw, tropical with a dry season, according to the Köppen classification (ALVAREZ et al., 2013). The soil at the site is classified as eutrophic Red Latosol (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2018) .

The evaluated area was cultivated during four cycles with experiments involving wastewater, which was applied to four different crops, namely, corn (November 2012--February 2013) (ALVES et al. , 2018) , cotton (June--November 2013) (ALVES, 2014) , common beans (April--June 2014) (SANTOS et al. , 2017) and pineapple (July 2015--March 2017) (OLIVEIRA, 2018) .

All crops were cultivated in the same area and in the same experimental plots involving five ART treatments (0, 50, 100, 150 and 200% of the ART dose limited by the reference element K^+ in the first 3 crops and 0, 100, 200, 300 and 400% of the ART dose limited by the reference element Na^+ in the pineapple plant) corresponding to 0 = clean water and mineral fertilization; 1 = 50; 2 = 100; 3 = 150 and 4 = 200% of the ART dose and 0: clean water and mineral fertilization; 1 = 100; 2 = 200; 3 = 300 and 4 = 400% of the ART dose), with these treatments arranged in a randomized complete block design, with four replications, which allowed the quantification of the ART doses totals applied in each of the experimental plots (Table 1).

Table 1. Partial doses of treated sanitary wastewater (ART, mm) were applied to sequential crops of corn (Nov/2012 to Feb/13), cotton (Jun to Nov/13), common bean (Apr to Jun/14) and pineapple (Jul/15 to Mar/17), and total doses were determined for each treatment.

Dose*	Corn	Cotton	Bean plant	Pineapple tree	Totals
0	0	0	0	0	0
1	61.2	103.2	46.1	117.3	327.8
2	122.0	200.0	91.7	234.1	647.8
3	180.5	302.9	137.8	351.4	972.6
4	240.2	399.7	184.3	468.3	1292.5

***Source:** Alves (2014), Alves et al. (2018), Santos et al. (2017), Oliveira (2018), adapted.

In all crop cycles preceding the evaluations, irrigation management aimed to maintain moisture at field capacity down to a depth of 0.5 m. Irrigation management was based on the daily reference evapotranspiration (ET_0), which was determined via the Penman–Monteith method (ALLEN et al., 2006) and used data from a meteorological station installed in the experimental area to meet the water demand of each crop. Because the water requirement is greater than the nutrients contained in the ART, clean water was supplemented in all the treatments via a drip irrigation system, which was used for both types of water, with emitters spaced 0.4 m apart and 0.9 m between lateral lines and with an average flow rate of 5.81 L h^{-1}.

To estimate the basic infiltration rate (VIB) and the hydraulic conductivity of the water in the soil (K_0), the concentric ring infiltration method was used, with measurements taken in each experimental unit (TEIXEIRA et al., 2017) , resulting in four repetitions. In search of an equation that best fits the curves of the data obtained in the infiltration tests, three empirical models were selected from among those available: Kostiakov, Kostiakov–Lewis and Horton (BRANDÃO et al., 2006) .

After generating a curve for each model, model comparison tests were performed according to Camargo and Sentelhas (1997), Willmott (1981), Willmott and Matsuura (2005) , aiming to define which model would best represent the field data, with Kostiakov having the best performance. Once the model was defined, the VIB was determined, assuming that infiltration stabilization occurred when the variation in velocities around the average of the last measured values was within ±10% in the 60-minute interval (BERNARDO; SOARES; MANTOVANI, 2006) .

Furthermore, since the stabilization time was above 3 h for most treatments, the infiltration rate was determined for a fixed time of 1.5 h (VI $_{1.5}$) to observe whether the infiltration response in the first half of the average stabilization time would be similar to the VIB response.

After the basic infiltration rates were determined, an empirical model described by Bernardo , Soares and Mantovani (2006) was used was used to estimate the saturated hydraulic conductivity (K_0) of each plot.

Soil samples were collected to determine apparent density via the volumetric ring method, with two samples collected in layers 0 to 0.2 m; 0.2 to 0.4 m; 0.4 to 0.6 m; and 0.6 to 0.8 m (TEIXEIRA et al., 2017) . In addition, duplicate samples with deformed structures were also collected to determine the soil water retention curve via the Richards chamber method at the same depths mentioned above (TEIXEIRA et al., 2017) , with moisture values adjusted via the van Genuchten equation (1980).

The deformed samples were used to determine the electrical conductivity of the saturated soil extract (CE), water-dispersed clay (ADA) and percentage of exchangeable sodium (PST) (TEIXEIRA et al., 2017) .

Using the retention curves and layer densities of each experimental unit (eu), the moisture content at field capacity (θ_{cc}) and at the permanent wilting point (θ_{pm}) were calculated and obtained at 20 kPa, a pressure defined by the basin method (BERNARDO; SOARES; MANTOVANI, 2006) and at 1500 kPa. In addition, the total soil water availability (TWA) was also calculated.

The variables used to study soil changes due to use and ART were VIB, VI $_{1.5}$, K_0, CE_{es}, PST, ADA, DTA, θ_{cc}, and θ_{pm}. The data were interpreted through preliminary analysis of variance at the 5% significance level of the F test. For those variables whose source of variation, ART dose, was significant, regression analysis was applied, with an F test at up to 5% significance. The regression models were chosen on the basis of the significance of the F test, the coefficients of determination (R^2), and the ability to explain the phenomenon studied, in addition to the application of the t test for the parameters, at the 5% significance level. Statistical analysis was performed with the aid of the SISVAR program (FERREIRA, 2011) .

5 RESULTS AND DISCUSSION

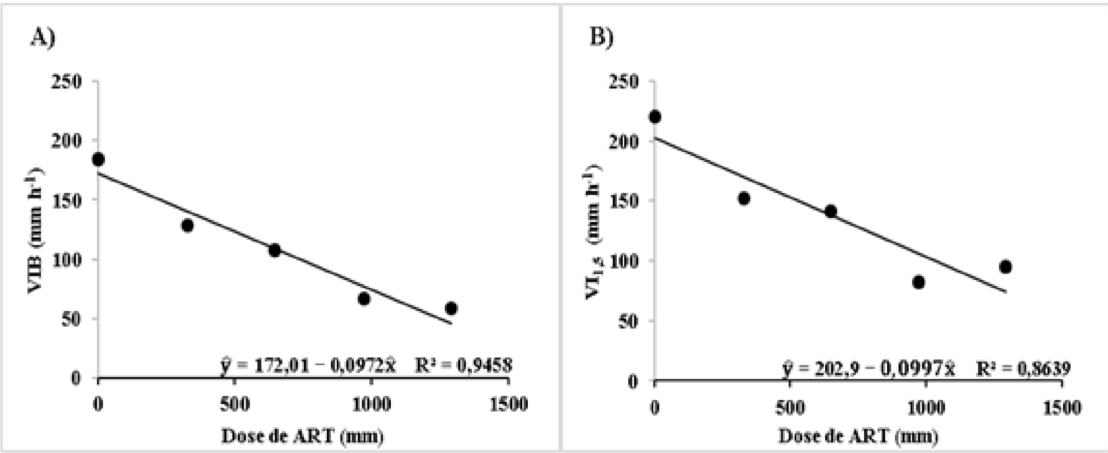
The basic infiltration rate (VIB) and infiltration rate at a fixed time of 1.5 h (VI $_{1.5}$) changed ($p < 0.05$) (Table 2), which was explained by decreasing linear regressions (Figure 1). There was a reduction in infiltration as the ART depth increased, possibly due to the characteristics of ART, which can alter the dynamics of soil water in different layers, mainly due to excess sodium beyond irrigation control in management (SANTOS et al., 2017 ; SANTOS et al ., 2015 ; CORRÊA et al ., 2003). Irrigation management at a preestablished depth can leach fertigated components, such as sodium, to the limit of the depth at which it is intended to increase to field capacity, which in the studied area can reach 0.4 m. If an imbalance occurs between monovalent ions, changes in water flow in the soil can be triggered (SANTOS et al., 2015) .

Table 2. Summary of the analysis of variance results for the basic infiltration rate (VIB), infiltration rate at 1.5 h ($VI_{1.5}$) and hydraulic conductivity (K_0) under different doses of treated wastewater (ART) at the end of four cultivation cycles.

FV	GL	Mean Square		
		VIB (mm h $^{-1}$)	$VI_{1.5}$ (mm h $^{-1}$)	K_0 (cm h $^{-1}$)
Block	3	2935.6	2267.1	5.50
ART	4	10421.5 *	12010.1 *	58.64 *
Residue	12	14128.71	17359.77	6.62
CV (%)		31.48	27.51	31.48
Overall average		109.01	138.27	8.18

FV = source of variation; GL = degrees of freedom; CV = coefficient of variation.

Figure 1. Basic infiltration rate (A) and fixed-time infiltration rate of 1.5 h (B) estimated by the Kostiakov model for doses of treated sanitary wastewater (ART) at the end of four cultivation cycles.



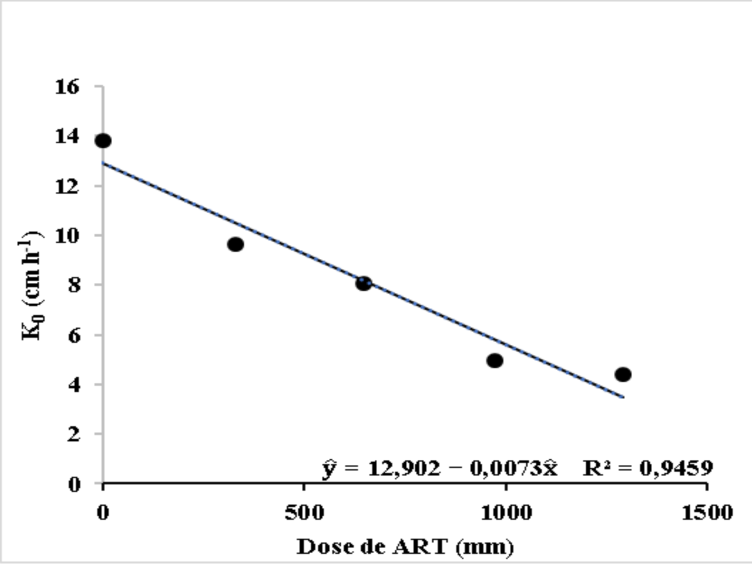
*significant at the 5% level according to a t test.

The $VI_{1.5}$ remained close to the VIB, indicating that by the 1.5-h time point, infiltration was numerically approaching that of saturated soil. This indicates good soil infiltration capacity even for the highest ART doses.

A value of $^{-1}$ and 0.0997 mm h $^{-1}$ was observed for each millimeter of ART added to the soil. In VIB and $VI_{1.5}$, respectively (Figure 1), infiltration can be considered high in all the treatments evaluated, including the one with the greatest reduction (T4), since according to Bernardo, Soares and Mantovani (2006), an infiltration rate above 30 mm h $^{-1}$ is considered high in crop areas. Even so, care is recommended in the sequential use of the ART dose applied in fertigation, since the VIB presented by the plots that received the highest doses applied (T4) was much lower than that of the treatment that did not receive ART (T0).

The saturated hydraulic conductivity (K_0) was also influenced ($p>0.05$) by the applied ART depth (Table 2), which was explained by a decreasing linear regression (Figure 2), similar to VIB.

Figure 2. Hydraulic conductivity (K_0) influenced by different doses of treated sanitary wastewater (ART) at the end of four cultivation cycles.



*significant at the 5% level according to a t test.

There was a reduction in K_0 from moderately fast to moderate according to the classification proposed by Ferreira (1998) , which stipulated limits for classification (very fast = greater than 25 cm h^{-1}; fast = from 12.5 to 25 cm h^{-1}; moderately fast = from 6.25 to 12.5 cm h^{-1}; moderate = from 2.0 to 6.25 cm h^{-1}; moderately slow = from 0.5 to 2.0 cm h^{-1}; slow = from 0.125 to 0.5 cm h^{-1}; and very slow = less than 0.125 cm h^{-1}).

The ART has suspended solids, significant levels of electrolytes, dissolved organic matter and high biochemical oxygen demand (BOD), which may explain the changes in K_0 even without significant changes being noted for this variable linked to the soil structure (BEDBABIS *et al.* , 2014; MHASKE; NIKAM, 2017; VARALLO *et al.* , 2010) .

Even with a linear reduction of 0.0073 cm h^{-1} for each 1 mm of ART added to the soil (Figure 2), K_0 still remained at satisfactory levels, without risks to water movement in the soil, since in semiarid regions, there is a compromise of K_0 in soils whose rates are below 0.6 cm h^{-1} (SCHACHT; MARSCHNER, 2014) . However, the lowest K_0 found in the present work was 3.47 cm h^{-1}.

The infiltration, hydraulic conductivity, soil moisture at the upper (field capacity, U_{cc}) and lower (U_{pm}) limits, and total water availability (TWA) depend directly on the soil type and structure, with the soil in the studied area falling into the sandy-clay loam textural class in the 0–0.2 m layer, with increasing clay content in the profile, reaching the clay loam class in the 0.6–0.8 m layer (BRAZILIAN AGRICULTURAL RESEARCH COMPANY, 2018; SANTOS et al. , 2015) .

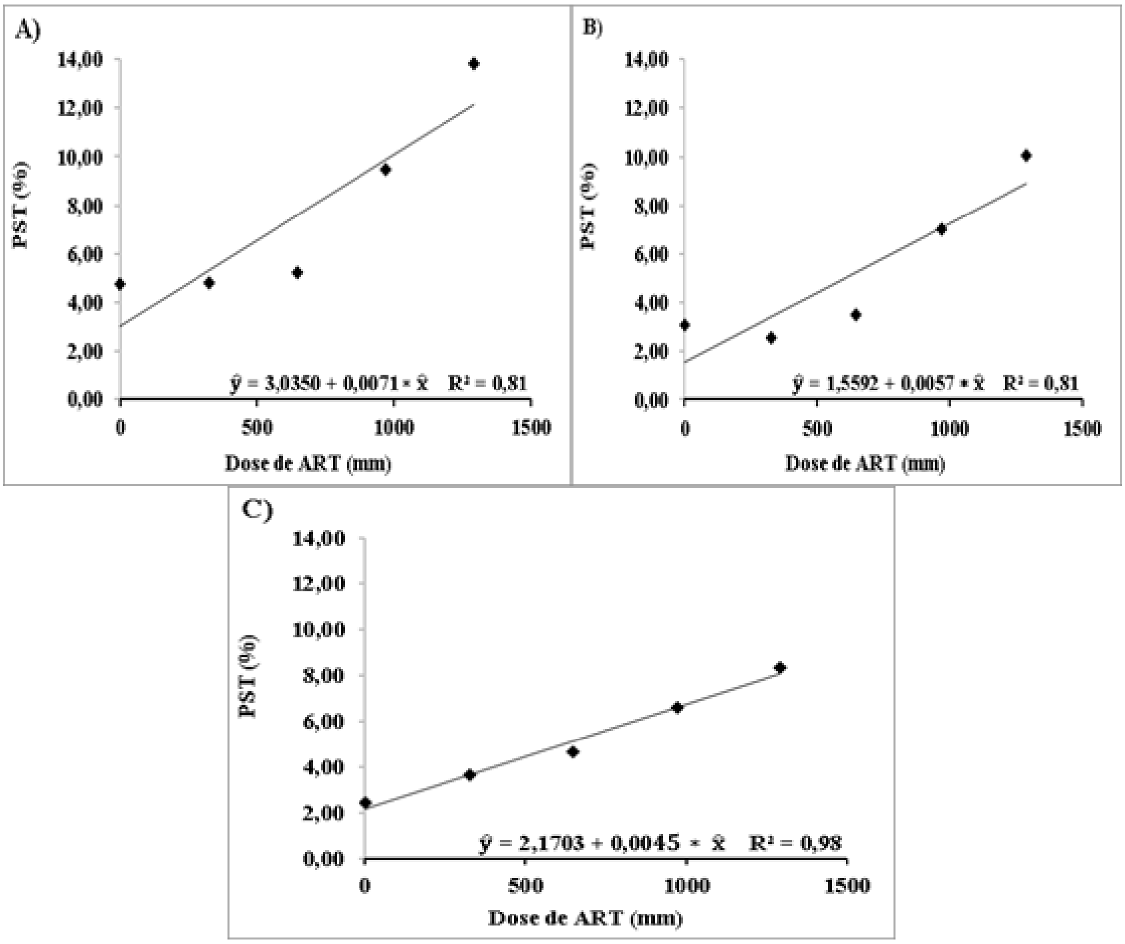
Significant differences were observed for PST in the three layers analyzed (Table 3), represented by increasing linear regressions (Figure 3). There was an increase in the PST of 0.0071%, 0.0057%, and 0.0045% for each mm of ART added to the soil in the 0–0.2, 0.2–0.4, and 0.4–0.6 m layers, respectively. These responses can be explained by the sodium concentration present in the ART, as verified in the works developed throughout the cultivation cycles in the experimental area (ALVES, 2014; ALVES et al., 2018; OLIVEIRA, 2018; SANTOS et al., 2017) .

Table 3. Summary of analysis of variance for electrical conductivity of soil saturation extract (EC, etc.), percent exchangeable sodium (PST), water-dispersible clay (ADA), moisture at wilting point (θpm), moisture at field capacity (θcc) and total water availability (DTA), performed on the soil profile at the end of four cropping cycles.

			Mean Square					
Prof.	**FV**	**GL**	**CE is**	**PST**	**ADA**	**θ pm**	**θ cc**	**DTA**
			dS m $^{-1}$	**%**	**g kg $^{-1}$**	**cm ^{3} cm $^{-3}$**	**cm ^{3} cm $^{-3}$**	**mm cm $^{-1}$**
0 - 0.2	Block	3	0.01	0.0004	1932,36	0.0004	0.0008	0.03
	Trat.	4	0.026 ^{ns}	0.00008 *	266.83 ^{ns}	0.0001 ^{ns}	0.0007 ^{ns}	0.08 ^{ns}
	Res.	12	0.13	0.0001	447.56	0.0001	0.0010	0.16
CV(%)			31.6	9.44	14.1	9.44	12.54	23.29
Average			0.32	0.13	150.35	0.13	0.25	1.74
0.2 - 0.4	Block	3	0.005	62.71	3748.8	0.0001	155.3	0.12
	Trat.	4	0.015 ^{ns}	33.18 *	218.03 ^{ns}	0.0002 ^{ns}	0.0011 ^{ns}	0.35 ^{ns}
	Res.	12	0.012	17.39	581.5	0.0001	0.0008	0.240
CV(%)			32.40	79.50	14.08	7.61	10.39	26.58
Average			0.34	5.24	171.25	0.14	0.26	1.86
0.4 - 0.6	Block	3	0.03	37.16	1908.91	0.0003	0.0009	0.10
	Trat.	4	0.04 ^{ns}	21.99 *	637.47 ^{ns}	0.0004 ^{ns}	0.0006 ^{ns}	0.21 ^{ns}
	Res.	12	0.02	12.71	1290.69	0.0003	0.0017	0.35
CV(%)			31.15	69.64	18.97	9.77	14.06	30.59
Average			0.40	5.12	199.95	0.17	0.29	1.94
0.6 - 0.8	Block	3	0.02	-	1987.99	0.0001	0.0010	0.11
	Trat.	4	0.011 ^{ns}	-	8620.12 ^{ns}	0.0005 ^{ns}	0.0003 ^{ns}	0.31 ^{ns}
	Res.	12	0.02	-	5963.22	0.0002	0.0170	0.20
CV(%)			30.12	-	37.45	9.86	12.63	20.93
Average			0.48	-	206.18	0.16	0.30	2.15

FV = source of variation; GL = degrees of freedom; CV = coefficient of variation. * Significant at the 5% level; ^{ns,} not significant; F test

Figure 3. Percentage of exchangeable sodium (PST) in three soil layers (0–0.2 m, A; 0.2–0.4 m, B; and 0.4–0.6 m, C) influenced by different doses of treated wastewater (ART) at the end of four crop cycles.



[*] significant at the 5% level according to the F test.

Although the PST increased in the ART treatment group, no significant difference was observed for ADA or CE, which were not influenced by ART (Table 3). This can be explained by the PST values remaining below 15% (AYERS; WESCOT, 1991; PIZARRO CABELLO, 1985) even with the highest doses of ART.

This reinforces the thesis of maintaining the fertigation criterion based on the reference element to define the ART dose to avoid future problems in soil structuring arising mainly from sodium in relation to other ions, which can more significantly reduce the VIB and $VI_{1.5}$ (Figure 1).

Management conditions with salinizing sources can increase salt and dispersant element contents in the soil, which are indirectly quantified by the electrical conductivity of the saturated stratum (EC) and the percentage of exchangeable sodium (PST), both of which are used to classify soils as normal, saline, sodic or saline-sodic (PIZARRO CABELLO, 1985) .

The ratio between PST and EC can promote clay dispersion (ADA), altering the soil structure (PIZARRO CABELLO, 1985) . Therefore, these variables were also quantified.

The nonsignificance ($p > 0.05$) of θ_{cc}, θ_{pm}, and DTA (Table 3) in any of the evaluated layers confirms the safety of using the ART dose criterion on the basis of a reference element. Even so, although the responses were not different between layers, higher DTA values were observed in the deeper layers, possibly because irrigation management tends to leach ions into these soil layers.

The results for $_{CEs}$ were satisfactory since $CE_{es\ values}$ below 1.3 dS m^{-1} do not pose a risk of reducing the productivity of the main agricultural crops (AYERS; WESCOT, 1991) . Furthermore, the averages presented in the $CE_{evaluation}$ were very low, not exceeding 0.5 dS m^{-1}.

As there was no effect of ART on clay dispersion (Table 3), the results of U_{cc}, U_{pm} and DTA observed are plausible, since clay dispersion reduces the number of macropores in the soil and consequently increases the number of micropores, altering the availability of water in the soil and consequently increasing the moisture content at the field capacity and wilting point (LOY et al., 2018; MARCHUK; MARCHUK, 2018) .

6 CONCLUSIONS

The use of treated sanitary wastewater in fertigation does not compromise the movement and retention of water under the conditions evaluated in this study, given that the changes made did not exceed the limits considered safe, according to the literature.

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8 REFERENCES

ALLEN, RG; PEREIRA, LS; RAES, D.; SMITH, M. **Crop evaporation: guides for determining crop water requirements** . v. 56. Rome: Food & Agriculture Org., 2006.

ALVARES, CA; STAPE, JL; SENTELHAS, PC; GONÇALVES, JL de M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift** , Stuttgart, Germany, v. 22, no. 6, p. 711–728, 2013.

ALVES, IS **Competition of cotton cultivars fertigated with treated sanitary wastewater.** 2014. 28 p. Final course work (Monograph) – Agronomy Course, State University of Montes Claros, Janaúba-MG, 2014.

ALVES NETO, AJ; LANA, MC; RAMPIM, L.; COSTA, LADM; COPPO, JC ALVES, AG Swine wastewater on soybean and second-crop corn productivity: use and economic viability. **Scientia Agraria Paranaensis** , Marechal Cândido Rondon , v. 15, n. 3, p. 350-357, 2016.

ALVES, PFS; SANTOS, SR; KONDO, MK; ARAÚJO, ED; OLIVEIRA, PM Corn fertigation with treated sanitary wastewater: growth and production. **Sanitary and Environmental Engineering** , Rio de Janeiro, v. 23, n. 5, p. 833-839, v. 2018.

NATIONAL WATER AGENCY (Brazil). **Sewage Atlas** : Decontamination of river basins . Brasília, DF: ANA, 2017.

AYERS, RS; WESCOT, DW **Water quality in agriculture** . 1st ed. Campina Grande: UFPB, 1991. (FAO Studies Irrigation and Drainage, 29).

BEDBABIS, S.; ROUINA, BB; BOUKHRIS, M.; FERRARA, G. Effect of irrigation with treated wastewater on soil chemical properties and infiltration rate. **Journal of Environmental Management** , London, vol. 133, np. 45-50, 2014.

BERNARDO, S.; SOARES, AA; MANTOVANI, EC **Irrigation Manual** . 8th ed. Viçosa, MG: UFV, 2006. 625 p.

BRANDÃO, VS; CECÍLIO, RA; PRUSKI, FF; SILVA, DD **Water infiltration into the soil** . 3rd ed. Viçosa, MG: 2006.

BRAZIL. Ministry of the Environment. CONAMA Resolution 357, of March 18, 2005. Provides for the classification of water bodies and environmental guidelines for their classification, as well as establishes the conditions and standards for the discharge of effluents, and provides other measures. **Official Gazette of the Union** : section 1, Brasília, DF, year number, no. 53, p. 58-63, March 18, 2005. Available at: < https://www.icmbio.gov.br/cepsul/images/stories/legislacao/Resolucao/2005/res_conama_357_2005_classificacao_corpos_agua_rtfcda_altrd_res_393_2007_397_2008_410_2009_430_2011.pdf>. Accessed on: November 25, 2018.

CAMARGO, AP; SENTELHAS, PC Performance evaluation of different methods for estimating potential evapotranspiration in São Paulo State, Brazil. **Brazilian Journal of Agrometeorology** , Santa Maria-RS, v. 5, n. 1, p. 89-97, 1997.

CARVALHO, N.; HENTZ, P.; SILVA, JM; BARCELLOS, AL Reuse of wastewater. **Environmental Monographies Journal** , Santa Maria, v. 14, n. 2, p. 3164-3171, 2014.

CORRÊA, MM, KER, JC; MENDONÇA, ES; RUIZ, HA; BASTOS, RS Physical, chemical and mineralogical attributes of soils from the Várzeas de Sousa region (PB). **Brazilian Journal of Soil Science** , Viçosa, v. 27, n. 2, p. 311-324, 2003.

EMBRAPA. **Brazilian Soil Classification System** . 5th ed. Brasília, DF: Embrapa, 2018.

FERREIRA, D. F. Sisvar: a computational system for statistical analysis. **Science and Agrotechnology** , Lavras, v. 35, n. 6, p. 1039-1042, 2011.

FERREIRA, PA **Drainage of Agricultural Lands** . 3rd ed. Brasília, DF: ABEAS, 1998.

HOMEM, BGC; ALMEIDA NETO, OB; CONDE, MS; SILVA, MD; FERREIRA, IM Effect of prolonged use of swine wastewater on the chemical and physical properties of a Red–Yellow Latosol. **Scientific** , Jaboticabal, v. 42, n. 3, p. 299-309, 2014.

LIBUTTI, A.; GATTA, G.; GAGLIARDI, A.; VERGINE, P.; POLICE, A.; BENEDUCE, L.;

DISCIGLIO, G.; TARANTINO, E. Agro-industrial wastewater reuse for irrigation of a vegetable crop succession under Mediterranean conditions. **Agricultural Water Management** , Amsterdam, v. 196, p. 1-14, 2018.

LOY, S.; ASSI, AT; MOHTAR, RH; MORGAN, C.; JANTRANIA, A. The effect of municipal treated wastewater on the water holding properties of a clayey, calcareous soil. **Science of the Total Environment** , Amsterdam, v. 643, p. 807-818, 2018.

MARCHUK, S.; MARCHUK, A. Effect of applied potassium concentration on clay dispersion, hydraulic conductivity, pore structure and mineralogy of two contrasting Australian soils. **Soil and Tillage Research** , Amsterdam, v. 182, no. April, p. 35-44, 2018.

MATOS, AT; MATOS, MP **Wastewater Disposal in Soil** . 1st ed. Viçosa, MG: UFV, 2017. v. 1.

MATOS, AT; MARTINS, PO; LO MONACO, PAV Chemical Changes in Soil After Fertigation of Mombaça Grass with Tannery Wastewater. **Journal of Agricultural Engineering** , Viçosa, v. 22, n. 2, p. 128-137, May 2014.

MINAS GERAIS. State Council for Environmental Policy. State Council for Water Resources of the State of Minas Gerais. Joint Normative Deliberation COPAN/CERH No. 001, of May 5, 2008. Provides for the classification of water bodies and environmental guidelines for their classification, as well as establishes the conditions and standards for the discharge of effluents, and contains other provisions. **Executive Gazette of Minas Gerais:** Belo Horizonte, May 20, 2008. Available at: < http://www.siam.mg.gov.br/sla/download.pdf?idNorma=8151> . Accessed on: November 25, 2018.

MHASKE, AR; NIKAM, PJ Impact of treated domestic sewage irrigation on crop yield, plant uptake and soil properties in Central India. **International Journal of Technology & Engineering** , Bangkok, vol. 7, no. 2, p. 79-92, 2017.

NASCIMENTO, JDS; FIDELIS FILHO, J. Growth, production and soil chemical changes in cotton irrigated with treated sewage water. **Caatinga Journal** , Mossoró, v. 28, n. 2, p. 36–45, 2015.

OLIVEIRA, FS **Fertigation of pineapple with treated sanitary wastewater** . 2018. Thesis (Doctorate in Agronomy) – State University of Montes Claros, Montes Claros, 2018.

PIZARRO CABELLO, F. **Agricultural drainage and recovery of saline soils** . 2nd ed. Madrid: Agrícola Española, 1985. 542p.

SANTOS, SR; SOARES, AA; KONDO, MK; ARAÚJO, ED; CECON, PR Growth and production of cotton fertigated with sanitary wastewater in the semiarid region of Minas Gerais. **Irriga** , Botucatu, v. 21, n. 1, p. 40-57, 2016.

SANTOS, SR; KONDO, M.K.; OLIVEIRA, PM; ANDRADE JÚNIOR, IO; MATOS, AT Short-term changes in soil properties due to sanitary wastewater irrigation used as a potassium source . **Australian Journal of Crop Science** , Brisbane, vol. 9, no. 8, p. 713-720, 2015.

SANTOS, SR; RIBEIRO, DP; MATOS, AT; KONDO, M.K.; ARAÚJO, ED Changes in soil chemical properties promoted by fertigation with treated sanitary wastewater. **Agricultural Engineering** , Jaboticabal, v. 37, no. 2, p. 343-352, 2017.

SCHACHT, K.; MARSCHNER, B. Treated wastewater irrigation effects on soil hydraulic conductivity and aggregate stability of loamy soils in Israel. **Journal of Hydrology and Hydromechanics** , Warsaw, vol. 63, no. 1, p. 47-54, 2014.

SILVA, TL Wastewater quality for reuse in irrigated agriculture. **Irriga Botucatu** , Botucatu, v. 1, n. 1, p. 101-111, 2018.

TEIXEIRA, PC; DONAGEMA, GC; FONTANA, A.; TEIXEIRA, WG **Manual of Soil Analysis Methods** . Brasília: Embrapa, 2017.

VARALLO, ACT; CARVALHO, L.; SANTORO, BL; SOUZA, CF Changes in the attributes of a Red–Yellow Latosol irrigated with reused water. **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grande, v. 14, n. 4, p. 372-377, 2010.

VAN GENUCHTEN, MT A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. **Soil science society of America journal** , New York, v. 44, no. 5, p. 892–898, 1980.

WILLMOTT, CJ On the validation of models. **Physical geography** , London, vol. 2, no. 2, p. 184-194, 1981.

WILLMOTT, C.J.; MATSUURA, K. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. **Climate research** , Oldendorf, vol. 30, no. 1, p. 79-82, 2005.