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SOIL PHYSICAL ATTRIBUTES IN CHEMIGATED BANANA PLANTATION WITH WASTEWATER

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ABSTRACT: The feasibility of using sewage wastewater as a water and nutrient source for plants is an alternative to harness agricultural natural resource, observing its influence on the organic matter dynamics and soil energy. Our objective here was to evaluate the effects of applying different doses of effluent from a sewage treatment plant, in Janaúba – MG, Brazil, over the physical attributes of a soil grown with "Prata Anã" banana. From soil sample collection at depths of 0-20, 20-40, and 40-60 cm, we determined the following soil properties: soil density, total porosity, macroporosity, microporosity, organic matter, clay dispersed in water and stability of soil aggregate. The experimental design was in randomized blocks with four repetitions. Wastewater raising doses promoted increase in suspended solids, contributing to macroporosity reduction at 20-40 and 40-60 cm depths; as well as a reduction in organic matter within 0-20 cm layer. Clay dispersal was observed in the depths of 0-20 cm, being derived from an increase in sodium content. Concurrently, there was a reduction of soil aggregate stability.

KEYWORDS: *Musa* spp, agricultural reuse of effluents, environmental sanitation, semi-arid.

ATRIBUTOS FÍSICOS DO SOLO EM BANANAL FERTIRRIGADO COM ÁGUA RESIDUÁRIA SANITÁRIA TRATADA

RESUMO: A utilização de água residuária proveniente do tratamento de esgoto, como fonte hídrica e nutricional para as plantas, é uma alternativa para racionalizar o aproveitamento do recurso natural na agricultura, observando-se sua influência sobre a dinâmica da matéria e da energia no solo. O objetivo deste trabalho foi avaliar os efeitos da aplicação de diferentes doses de efluente da estação de tratamento de esgoto de Janaúba - MG, sobre os atributos físicos de um solo cultivado com banana 'Prata-Anã'. A partir da coleta de amostras de solo, nas profundidades de 0-20; 20-40 e 40-60 cm, foram avaliados os seguintes atributos: densidade do solo, porosidade total, macroporosidade, microporosidade, matéria orgânica, argila dispersa em água e a estabilidade de agregados do solo. O delineamento experimental foi o em blocos casualizados, com quatro repetições. O aumento das doses de água residuária sanitária tratada no solo promove: a) Incremento nos sólidos suspensos aportados ao solo, o que contribui para a redução da macroporosidade nas profundidades de 20-40 e 40-60 cm do solo; b) Redução da matéria orgânica na profundidade de 0-20 cm do solo; c) Aumento do aporte de sódio, o que determina a dispersão de argilas na profundidade de 0-20 cm, e d) Redução da estabilidade de agregados do solo.

PALAVRAS-CHAVE: *Musa* spp., reúso agrícola de efluentes, saneamento ambiental, semiárido.

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INTRODUCTION

Having in perspective the reduction of hydric offer in terms of not only quantity but also quality for the most varied means, the adequate use and management of water has become indispensable. The use of urban waste, mainly the domestic sewage in agriculture is an important source of water and nutrients. Their inadequate destination may contribute to the increase of costs concerning water treatment headed for human consumption. According to VARALLO et al. (2012), the hydric bodies are considered natural purifier of the man-generated waste. However, this very common practice is compromises the quality of the environment.

Besides that, the destination of domestic sewage in watercourses is pointed out (BARROSO & WOLFF, 2011) as one of the main causes of diseases related to hydric association, especially in areas close to urban centers. The use of domestic sewage in agriculture as a source of water and/or nutrients would be an alternative to minimize its inappropriate destination. Nevertheless, this practice must be done with criteria. Frequent applications in association to high levels might influence the physical attributes of the soil, such as its density, structure and stability of aggregates, the aeration, draining and water retention (ERTHAL, et al. 2010; SAMPAIO et al., 2010 e SOUZA et al., 2010).

Knowing the physical attributes alterations of the soil is fundamentally important because they cause an impact on the use and handling of it, providing information about its quality and productive capacity (ARATANI et al., 2009).

Another factor to be considered when handling the wastewater is the crop to be used. The banana tree besides being a highly demanding plant in nutrients is also sensitive to growing factors concerning the soil physical traits, such as the aeration, soil density, water retention and mechanical resistance to growing roots (COSTA et al., 2011; MIOTTI et al., 2013).

Our objective is to evaluate the behavior of the soil physical attributes influenced by the use of treated wastewater (TWW) in soils cultivated with banana tree OF "Prata Anã" variety.

MATERIAL AND METHODS

This procedure was carried out in the experimental area of the Sewage Treatment Plant (ETE) of the MINAS GERAIS Sewage Company, COPASA, MG in Janaúba – MG, Brazil (15º 49' 53" S, 43º 16' 20" W, altitude of 540 m). Local climate is tropical with dry winter (Aw) according to Köppen.

The soil used in the experiment is classified as a eutrophic Red Latosol (Oxisol) (EMBRAPA, 2013). The area showed anthropic degradation signs, an evidence for a poor handling pasture and soil compaction according to Table 1. This way, subsoiling, aeration, harrowing, and ridging were done before planting.

The experimental design was a randomized complete block with four replications. Treatments consisted of different doses of treated wastewater (TWW) from a sewage treatment plant (STP), using as reference an annual ceiling (AC) of 150 kg ha^{-1} of sodium (Na) (LARCHER, 2005) in the soil. They were named as T1: control (clean water + mineral fertilizing); T2: 70 %; T3: 130 %; T4: 170 % and; T5: 200 % of TWW in relation to AC reference.

The sewage treatment plant of Janaúba performs a preliminary treatment (grate and grit chambers), Parshall flume with an ultrasonic flow measurer, upflow anaerobic sludge blanket (UASB), facultative pond and two other ponds for sequential maturation with treatment capacity under continuous flow of up to 48.4 L s^{-1}.

TABLE 1. Soil physical and chemical properties (eutrophic Red Latosol – Oxisol) at different depths before banana orchard planting.

Depth	**Ds**	**Dp**	**Pt**	**VCS**	**CS**	**MS**	**FS**	**VFS**	**Total Sand**	**Silt**	**Clay**
(m)	g cm^{-3}		m^{3} m^{-3}	g kg^{-1}							
0 - 20	1.77	2.58	0.31	20	85	150	180	86	521	185	294
20 - 40	1.66	2.54	0.34	20	75	143	177	79	494	172	334
40 - 60	1.57	2.53	0.37	19	67	126	153	75	441	157	403
60 - 80	1.52	2.62	0.42	19	62	109	144	78	411	210	379
Depth	**pH**	**[1]OM**	**[2]P**	**[2]K**	**[2]Na**	**[3]Ca**	**[3]Mg**	**[3]Al**	**[4]H+Al**	**[5]BS**	**[6]T**
(cm)	(H_2O)	dag kg^{-1}	mg dm^{-3}		cmol$_c$ dm^{-3}						
0 - 20	6.2	1.3	2.3	260	0.1	2.8	0.9	0	2.2	4.5	6.7
20 - 40	5.5	0.7	2.0	140	0.1	2.2	0.7	0	2.2	3.4	5.6
Depth	**[7]V**	**[8]m**	**[9]B**	**[2]Cu**	**[2]Fe**	**[2]Mn**	**[2]Zn**	**[10]P-rem**	**[11]EC**		
(cm)	**%**		**mg dm^{-3}**					**mg L^{-1}**	**dS m^{-1}**		
0 - 20	67	0	0.3	1.0	23.7	10.8	0.8	35.2	0.3		
20 - 40	61	0	0.4	0.9	24.8	3.9	0.4	30.6	0.2		

Ds: soil bulk density; Dp: particle density; Pt: total porosity; VCS: very coarse sand; CS: coarse sand; MS: medium sand; FS: fine sand; VFS: very fine sand; [1]Organic matter determined through colorimetry; [2]Mehlich Extractor-1; [3]KCl - 1 mol L^{-1}; [4]Estimator: SMP pH; [5]BS: base sum; [6]T: CEC at pH 7; [7]V: base saturation; [8]m: aluminum saturation; [9]Extractor: $BaCl_2$; [10]Remaining phosphorus, determined in balance solution of P; [11]EC: Electric conductivity of saturated soil extract, in proportion of 1 (soil): 0.5 (water).

We used "PRATA ANÃ" banana variety. The trees were planted on 05/05/2012, using micropropagated seedlings in a 3 x 2 spacing, having 4 rows with 6 plants per row, totalizing 24 plants per plot.

Fifteen days before, base fertilization was carried using a soil mixture with NPK formulation (4-30-10), simple superphosphate and FTE BR12. This was made aiming to supply N (22.8 kg ha^{-1}), P_2O_5 (200.0 kg ha^{-1}), K_2O (50.0 kg ha^{-1}), S (48.6 kg ha^{-1}), Ca (103.9 kg ha^{-1}), B (1.5 kg ha^{-1}), Cu (0.7 kg ha^{-1}), Mn (1.7 kg ha^{-1}), Mo (0.1 kg ha^{-1}) and Zn (7.5 kg ha^{-1}), within plantation furrows at the spacing previously defined.

The TWW applications started forty-one days after plantation (DAP) with a weekly application via irrigation system (micro sprinkling). After TWW application, water supplementation was made to fulfill plant demands. In the third month, chemical fertilizing was initiated via chemigation system with nitrogen and potassium, aiming at controlling and complementing treatments that received effluent for a balanced supply (similar doses) of these nutrients.

Irrigation was based on daily reference evapotranspiration (ET_0), calculated by the Penman-Monteith method (ALLEN et al., 2006), using data gathered in a portable meteorological station installed in an experimental area. By multiplying the ET_0 by the crop coefficient (K_c), the location coefficient (K_l) and the soil coefficient (K_S), we could obtain the crop evapotranspiration (ET_c). This value associated with application efficiency (E_a) and nozzle mean flow (q_a) are used to estimate gross and net depths, as well as working time. Micro sprinkling had an E_a equal to 97%, consisted of a nozzle with mean flow of 76 L h^{-1} at service pressure of 200 kPa, using one nozzle for every three plants. Other farming practices followed crop recommendations.

Simple TWW samples were collected monthly at the end of one of the lateral row during application time, and packed in appropriate recipients. They were properly identified and sent to the laboratory for analysis of total nitrogen, nitrogen ammonia, nitrate nitrogen, organic nitrogen, potassium, sodium, phosphorus, zinc, copper, iron, manganese, boron, chloride, cobalt, calcium, magnesium, electrical conductivity, chemical oxygen demand, biochemistry oxygen demand, oils and grease, total suspended soils, total coliforms, *Escherichia coli*, following methodologies described in APHA *et al.* (2012). Having in hand the results of TWW analysis from the previous month, chemigation depths were calculated together with the TWW in the respective treatments. In Table 2, we can see the mean chemical composition of the main elements of the wastewater during the time the experiment was being made.

TABLE 2. Chemical characteristics of treated wastewater provided by the Sewage Treatment Plant of Janaúba and collected from June 2012 to June 2014.

Characteristics	**Unit**	**Average**		**Standard deviation**
N_{total}	mg L^{-1}	47.6000	±	8.6364
N_{amon}	mg L^{-1}	35.7000	±	9.6572
N_{nit}	mg L^{-1}	1.0800	±	1.7207
N_{org}	mg L^{-1}	10.8200	±	8.0942
K	mg L^{-1}	33.9390	±	11.1534
Na	mg L^{-1}	84.3690	±	19.4586
P	mg L^{-1}	8.2180	±	1.6438
Zn^{*}	mg L^{-1}	0.0880	±	0.0601
Cu	mg L^{-1}	0.0080	±	0.0011
Fe	mg L^{-1}	0.6800	±	0.2875
Mn	mg L^{-1}	0.1000	±	0.0102
B	mg L^{-1}	0.0230	±	0.0084
Cl^{-}	mg L^{-1}	130.6000	±	28.2479
Co	mg L^{-1}	0.0010	±	0.0086
Ca	mg L^{-1}	19.1340	±	4.9072
Mg^{*}	mg L^{-1}	7.9630	±	3.7786
CE	dS m^{-1}	1.1280	±	0.1619
OCD_{total}	mg L^{-1}	174.8000	±	35.1715
OBD_{total}	mg L^{-1}	58.8800	±	16.8785
O&G	mg L^{-1}	11.0000	±	4.1227
pH		7.6040	±	0.2467
TSS	mg L^{-1}	70.2000	±	33.8934
TC	UFC (100 mL)$^{-1}$	5.01E+06	±	4.32E+06
E. coli	NMP (100 mL)$^{-1}$	9.60E+03	±	3.16E+05

N_{total}: total nitrogen; N_{amon}: nitrogen ammonia N_{nit}: nitrate nitrogen; N_{org}: organic nitrogen; K: potassium; Na: sodium; P: phosphorus; Zn: zinc; Cu: copper; Fe: iron; Mn: manganese; B: boron; Cl^{-}.chloride; Co: cobalt; Ca: calcium; Mg: magnesium; CE: electrical conductivity; OCD_{total}: oxygen chemical demand; OBD_{total}: oxygen biochemical demand; O&G: oil and grease; TSS: total suspended soils; TC: total coliforms; *E. coli*: *Escherichia coli*; *: Only quantified from 02/2013.

The supply of the main elements of TWW and nutrients supplied to the soil via fertigation, as well as wastewater depths and clean water in the planting period until 586 days after planting (DAP) are described in Table 3.

After 586 days of plantation, ditches to a depth of 60 cm were open in the central area of the experimental plots to collect soil samples at 0-20, 20-40 and 40-60 cm layers, for further physical hydric analysis of the soil. For doing so, an Uhland sampler and rings with known volumes were used.

For the aggregate stability analysis, samples with undisturbed structure in clod shape (approximately 7 cm diameter) were withdrawn.

The samples were wrapped in plastic film and packed in cardboard boxes, having shredded paper inside to preserve moisture and structure. Afterwards, they were taken to the laboratory. From the obtained samples, soil density (Ds), total porosity (Pt), macroporosity (MaPt), microporosity (MiPt) and water-dispersed clay (DC) were determined as recommended by EMBRAPA (2011). The soil organic matter was determined by the WALKLEY & BLACK (1934) method.

TABLE 3. Depths, nutrients and components supplied to the soil (eutrophic Red Latosol – Oxisol) at each treatment, from banana orchard planting up to the following 586 days.

Treatment	TWW	Rain	CI	Total
	Depths			
		mm		
Control	0	658.7	3190.2	3848.9
70	178.8	658.7	3011.4	3848.9
130	351.2	658.7	2839.0	3848.9
170	438.3	658.7	2751.9	3848.9
200	522.3	658.7	2667.9	3848.9

Nutrients supplied to the soil (kg ha^{-1})

Treatments	N_{total}			P_2O_5			K_2O			Na		
	MF	TWW	Total	MF	TWW	Total	MF	TWW	Total	MF	TWW	Total
Control	359.5	0.0	359.5	241.7	0.0	241.7	420.0	0.0	420.0	0.0	0.0	0.0
70	243.8	160.9	404.7	233.5	42.2	275.7	349.7	86.3	436.0	0.0	163.3	163.3
130	212.6	202.4	415.0	225.3	82.5	307.8	280.0	168.6	448.6	0.0	320.3	320.3
170	197.4	224.4	421.8	221.3	103.3	324.6	245.9	210.6	456.5	0.0	400.6	400.6
200	181.7	244.5	426.2	217.0	123.0	340.0	211.3	250.7	462.0	0.0	476.9	476.9

Components supplied to the soil (kg ha^{-1}) via TWW

Treatments	O&G			TSS		
	Year 1	Year 2	Total	Year 1	Year 2	Total
Control	0.0	0.0	0.0	0.0	0.0	0.0
70	15.4	5.1	20.5	110.7	34.3	145.0
130	30.4	9.8	40.2	220.5	66.4	286.9
170	37.4	12.3	49.7	273.2	84.6	357.8
200	44.8	14.8	59.6	326.7	100.3	427.0

TWW: Treated wastewater; Rain: effective precipitation; CI: complementary irrigation; Total: total depths applied to the experimental plots; MF: mineral fertilization; N_{total}: total nitrogen available to the crop; P_2O_5: phosphorus; K_2O: potassium; Na: sodium; O&G: oils and grease; TSS: total suspended soils; Control: clean water and mineral fertilization; 70: 70%; 130: 130%; 170: 170%; 200: 200% supply limit (LARCHER, 2005) of sodium in the soil through TWW (150 kg ha^{-1} year^{-1}).

The clods were manually crushed and sifted in a set of sieves with meshes of 8 and 2 mm. Later, clumps retained on the 2 mm mesh sieve were sorted into two subsamples with 25 g each. One of these samples was used to determine moisture content and the other was placed on a Petri dish with a damp filter paper. After 12 hours, these samples were taken for stirring in a vertical mixer (YODER), under a set of sieves (2, 1, 0.5, 0.25, 0.106 mm mesh) for 15 minutes, with 30 oscillations per minute. After that, the retained aggregates in each sieve were transferred to aluminum recipients, dried in an oven at 105-110 °C and then weighed.

According to the methodology proposed by KEMPER & ROSENAU (1986), the following soil aggregate indexes were determined: weighted mean diameter (WMD), geometric mean diameter (GMD), macro and micro aggregate percentages (MacAgr and MicAgr).

Data underwent variance analysis and, when F was significant at 5% probability, regression analysis was performed. For the comparison of treatment means against control, the Dunnett test was used at a 5% significance. Besides, the Person’s linear correlation analysis was held to check the correlation among the characteristics. Soil depths were compared separately.

RESULTS AND DISCUSSION

In general, the physical attributes influenced by TWW compared to clean water were DC, MaPt, WMD and GMD (Table 4).

Soil compaction highlighted by an elevated soil bulk density can be influenced by TWW as reported by SOUZA et al. (2010), who studied alterations in soil physical properties from sewage use. In the present study, Ds had no influence from wastewater compared to clean water (Table 4). However, it must be highlighted an elevated soil throughout all layers, with values above 1.7 g cm^{-3}.

In accordance with MARCOLIN & KLEIN (2011), farming soils have a great amplitude of density, because of specific physical characteristics like texture. In general, sand presents low specific surface compared to silt and clay fractions. Consequently, it also presents low aggregation capacity, which contributes to pore spacing reduction and soil density increase (KLEIN, 2008).

This way, soil density elevation comes from grain-size related factors such as a large amount of fine sand (FS) within total sand fraction in contrast to the other fractions as medium sand fraction (MS), coarse sand (CS) and very coarse sand (VCS) (Table 1). This result validate the findings of LUCIANO et al. (2012), who worked with two Humic Cambisols and two Litholic Neosols (Humic Litholic Nitosol and Dystrophic Litholic Neosol).

TABLE 4. Treatment means and Dunnett test for the soil physical properties (eutrophic Red Latosol - Oxisol) chemigated with treated wastewater (586 days after plantation).

Treatment	Ds	Pt	MaPt	MiPt	OM	DC	WMD	GMD	MacAgr	MicAgr
	g cm^{-3}		m^3 m^{-3}		dag kg^{-1}	g kg^{-1}	mm		%	
0-20 cm										
70	1.77	0.43	0.06	0.35	2.32*	130*	3.73	1.47	90.60	9.40
130	1.81	0.42	0.06	0.37	1.79	132*	3.45	1.37	88.74	11.26
170	1.72	0.46	0.08	0.37	1.78	139*	3.39	1.37	81.61	18.39
200	1.77	0.44	0.09	0.36	1.64	143*	3.50	1.35	84.55	15.45
Control	1.80	0.43	0.09	0.36	1.53	94	3.15	1.54	86.07	13.93
20-40 cm										
70	1.77	0.43	0.15*	0.30	1.39*	142	2.61	1.15	80.85	19.15
130	1.74	0.43	0.12	0.32	1.02	151	2.59	1.09	79.48	20.52
170	1.75	0.46	0.13*	0.31	1.08	152	2.48	1.05	82.53	17.47
200	1.82	0.41	0.11	0.30	1.06	131	2.26*	0.90*	76.87	23.13
Control	1.83	0.41	0.10	0.33	0.94	131	3.25	1.33	82.14	17.86
40-60 cm										
70	1.79	0.42	0.10*	0.32	0.61	156	1.52	0.83	72.52	27.48
130	1.84	0.40	0.07	0.34	0.52	167	1.94	0.94	78.43	21.57
170	1.88	0.40	0.08	0.33	0.77	158	1.98	0.92	73.22	26.78
200	1.87	0.38	0.05	0.33	0.79	151	1.63	0.88	76.82	23.18
Control	1.87	0.39	0.06	0.34	0.66	141	1.65	0.88	75.96	24.04

For each depth, means followed by an asterisk (*) differ from control by the Dunnett test at 5% significance. Ds: Soil bulk density; Pt: Total porosity; MaPt: Total macroporosity; MiPt: Total microporosity; OM: Organic matter; DC: Water-dispersed clay; WMD: Weighted mean diameter; GMD: Geometric mean diameter; MacAgr: Macro aggregates; MicAgr: Micro aggregates.

TABLE 5. Person´s linear correlations among soil physical properties (eutrophic Red Latosol – Oxisol) chemigated with treated wastewater.

	Pt	MaPt	MiPt	OM	DC	WMD	GMD	MacAgr	MicAgr
Ds	-0.88^{**}	-0.41^{**}	-0.1^{ns}	-0.31^{*}	0.07^{ns}	-0.4^{**}	-0.32^{*}	-0.15^{ns}	0.15^{ns}
Pt		0.45^{**}	0.15^{ns}	0.42^{**}	-0.03^{ns}	0.45^{**}	0.35^{**}	0.17^{ns}	-0.17^{ns}
MaPt			-0.55^{**}	-0.06^{ns}	0.06^{ns}	-0.01^{ns}	-0.07^{ns}	-0.14^{ns}	0.14^{ns}
MiPt				0.41^{**}	-0.06^{ns}	0.41^{**}	0.45^{**}	0.34^{**}	-0.34^{**}
OM					-0.37^{**}	0.72^{**}	0.65^{**}	0.51^{**}	-0.51^{**}
DC						-0.36^{**}	-0.39^{**}	-0.26^{*}	0.26^{*}
WMD							0.87^{**}	0.67^{**}	-0.67^{**}
GMD								0.64^{**}	-0.64^{**}
MacAg									-1.00^{**}

Ds: soil bulk density; Pt: total porosity; MaPt: total macroporosity; MiPt: total microporosity; OM: organic matter; DC: water-dispersed clay; WMD: weighted mean diameter; GMD: geometric mean diameter; MacAgr: macro aggregates; MicAgr: micro aggregates.

**, *: 1 and 5 % significance by t-test, respectively. ^{ns}: non-significant.

Soil total porosity (Pt), which is another important indicative of soil quality, was also not influenced by TWW applications in this present study. According to LIMA et al. (2007), the ideal total porosity is next to 0.5 m^3 m^{-3}. This study showed a Pt of 0.43, 0.43 and 0.39 m^3 m^{-3} for the depths of 0-20, 20-40 and 40-60 cm, respectively.

Macro porosity (MaPt) in the depths of 20-40 and 40-60 cm was superior in chemigated soil with the smaller TWW doses in relation to control (Table 4). However, in Figure 1A, we can observe a linear effect of macroporosity reduction at 0.0003 m^3 m^{-3} for each percentage unit of TWW dose increase.

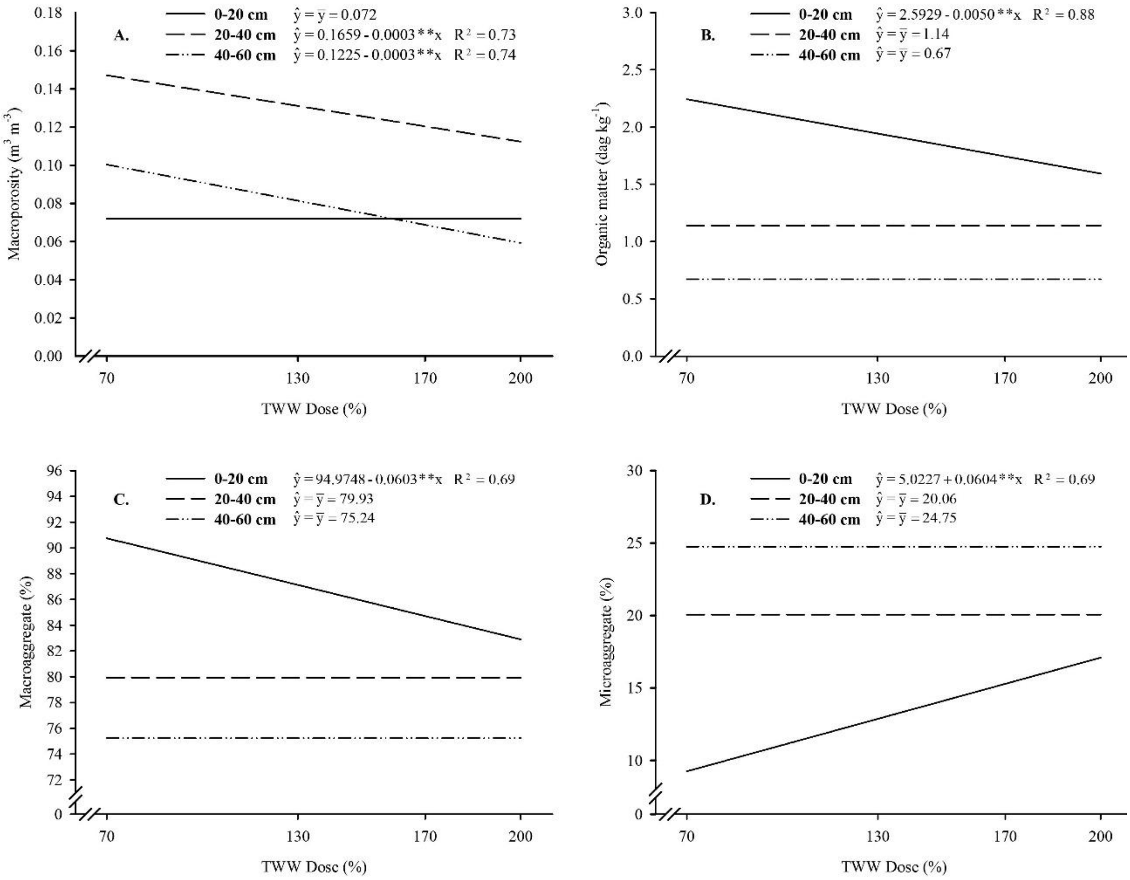

FIGURE 1. Macro porosity (A), organic matter (B), macro aggregate percentage (C) and micro aggregate (D) of a eutrophic Red Latosol (Oxisol) chemigated with treated wastewater.

Once macroporosity is essential for soil aeration and the development of plants, it can be concluded that high doses of TWW had a negative effect on soil quality. According to LIMA et al. (2007), macroporosity soil ranges between 0.170 and 0.250 m^3 m^{-3}, with its critical value at least 0.10 m^3 m^{-3} (KIEHL, 1979).

In accordance with SOUZA et al. (2010), in relation to the soil total porosity and its subdivisions, macroporosity and microporosity, the main interferences through the handling of wastewater would happen because of the suspended solids in sanitary sewer. This way, the relation with the highest values of MaPt obtained with the smaller doses of TWW are possibly related to the supply to the soil of organic substances that are part of TWW. However, the increase of TWW doses and consequent raise of supply to the total suspended solids (TSS) and oils and grease (Table 3). It can be associated to a possible dispersed clay eluviation at 0-20 cm, causing pore clogging and consequent porosity reduction at 20-40 cm and at 40-60 cm. RODRIGUES et al. (2010) observed that the samples of flooded soil with liquid detergent and oil presented soil porosity reduction.

No interference was verified by the adoption of wastewater use regarding microporosity. According to LIMA et al. (2007), soil microporosity is responsible for water storage and has its ideal value within a range between 0.250 and 0.330 m^3 m^{-3}. Therefore, our study shows that the obtained values for this attribute are in adequate levels overall (Table 4).

Concerning organic matter, it was verified that the TWW doses of 70% provided superior organic matter levels at 0-20 and 20-40 cm. Nevertheless, Figure 1B shows that at 0-20 cm, there was an OM reduction to 0.005 dag kg^{-1} for each percentage unit increase of TWW doses. Thus, TWW possibly provided soil fertility increase, which associated to organic components supplementation, especially those with low molecular weight, promoted an increment in microbial activity, as well as stimulation of native organic matter decomposition rates by the highest doses.

ANDRADE FILHO et al. (2013) working with a soil depth of 0-20 cm of a clayey in texture Cambisol cultivated with cotton crops, determined that the wastewater proportion in relation to the clean water mixture superior to 62,5% promoted the soil organic matter reduction. Similarly, SIMÕES et al. (2013) verified that domestic sewage effluent treated without dilution stimulates microbial activity in a Yellow Latosol (Oxisol) grown with castor bean.

THIESSEN et al. (2013) defined the priming effect as a positive stimulus to the microbial population growth with the addition of material rich in energy, causing an increase in decomposition rate due to enzymatic action of such microorganisms.

Nevertheless, in accordance with FORTES NETO et al. (2013), this organic matter reduction effect will remain until a pioneer community of metabolic active microorganisms is succeeded by microorganism communities with more stable metabolism that immobilize the carbon in the microbial biomass and contribute to elevate soil organic matter levels in a long-term.

Regarding DC levels, it was verified that at 0-20 cm, all treatments showed higher DC means compared to control, with mean increments of 38.30, 40.43, 47.87 and 52.13 % respectively for treatment using 70, 130, 170 and 200% TWW.

According to ERTHAL et al. (2010), the DC values are higher in superficial layers and tend to increase with time. The cumulative effect of sodium and potassium is the main cause for this change. In this way, the DC value increment observed are probably attributed to sodium supply whose values supplied to the soil reached variable quantities from 163.3 to 476.9 kg ha^{-1} among the treatments with the lowest (70) and the highest (200) TWW doses (Table 3).

For DIAS & BLANCO (2010), sodium presents the hydrated radius relatively large compared to the other elements, such as calcium and magnesium, being given significant potential to change the double diffuse layer (DDL) and, consequently soil physical behavior in face of wetting and drying cycles. As stated by MEURER et al. (2004), the dispersed clay in water may eluviate along soil profile and produce horizons richer in clay, as well as block micro pores reducing aeration and water infiltration.

The highest tested doses at 20-40 cm reduced aggregates stability, confirmed by the WMD and GMD indexes (Table 4). Table 4 shows that wastewater management had no influence on aggregate distribution (macro and micro aggregates). However, the regression analysis indicated a macro aggregate reduction of 0.06% and micro aggregate increase of 0.06% at 0-20 cm layer for each increase unit of TWW dose (Figures 1C and 1D).

According to VICENTE et al. (2012), stable aggregates in water restore soil porosity, influencing on infiltration and promoting an erosion resistance. Nonetheless, non-stable aggregates may disappear to the minimum impact of raindrops.

The soil stability increase has been attributed to organic matter increment (SOUZA et al., 2009; ANDERS et al., 2010). In this case, as OM content was reduced with the increase of TWW doses, it is believed that such reduction has contributed negatively to the aggregation index.

According to SOUSA NETO et al. (2009), all relevant factors to aggregate formation and stabilization have elevated relation with soil clay dispersion. This way, besides the OM reduction, the sodium supply increase caused by TWW with subsequent clay dispersion, may have been decisive to aggregate stability reduction. The negative correlations between DC and WMD, GMD and MaAgr contributed to this statement (Table 5).

CONCLUSIONS

The treated wastewater modifies the soil porosity distribution.

The macroporosity at deeper layers is reduced with elevated doses of treated wastewater supply.

The treated wastewater increments soil organic matter at superficial layers compared to clean water, being lower with increasing doses.

The increase in treated wastewater doses contributes to clay dispersion within superficial layers.

The chemigation with treated wastewater elevates the risk of soil loss by erosion due to aggregate stability reduction.

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