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Effects of Treated Wastewater on Soil Recovery in Degraded Semiarid Region

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Authors' contributions

This work was carried out in collaboration among all authors. Authors ELM and RFSS managed analyses of the study and the literature searches, performed the statistical analysis and wrote the first draft of the manuscript. Author VSF guided the study and corrected the final draft of the manuscript. Author SSM designed the study and provided the financial resources to the study development. All authors read and approved the final manuscript.

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ABSTRACT

This study aimed to evaluate the effect of treated wastewater application on soil organic matter and phosphorus recovery in a degraded soil in the semiarid region of Brazil. An experiment was carried out with irrigation of five caatinga forest species, in which three treatments were applied that consisted in the variation of the type and volume of water applied to the soil, being 7 L per week of tap water, 7 and 14 L per week of wastewater. After two years of irrigation, soil samples were taken and analyzed for soil organic matter and phosphorus. The organic matter content in the treatment with 14 L application of wastewater was five times higher than application of tap water in the superficial layer and 8 times higher in the sub-surface, respectively. From the results obtained, it can be considered that the use of wastewater from treated domestic sewage serve as an alternative for the recovery of the productive capacity of the soil by the increase in the organic matter and soil phosphorus contents. Irrigation with treated wastewater can provide a high increase in soil organic matter and phosphorus content up to 30 cm deep.

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1. INTRODUCTION

Soil degradation is a major environmental problem affecting 33% of the earth's surface, reaching around 42% of the world's population, causing the loss of soil productive capacity and food shortages [1]. Among the main causes of degradation is the removal of soil layers for civil construction, a common and very aggressive practice, which results in the total or partial removal of surface horizons and exposure of underlying layers causing direct impacts on soil quality and irreversible damage to its fertility [2] As an aggravating factor, environmental feasibility studies of mining and soil extraction, when carried out, are generally incipient and do not include soil recovery techniques [3].

In areas with severe water deficiency, the recovery of areas for agricultural purposes is more difficult, due to water limitations for the production of plant biomass. However, the use of water from domestic sewage treatment plants (ETE) has been shown to be an appropriate practice, both in forest and forage production, and in the recovery of degraded soils [4,5].

Although the use of these water sources present technical, legal, economic and social challenges, because the wastewater has variable contents of suspended solids, organic matter and chemical elements, the possibility of recovering nutrient levels and enabling biomass production presents as a promising alternative, although no published works have been found in this regard on a field scale. Some studies have evaluated the transport of wastewater solutes in various soil classes, but limited to soil columns or pots [6,7].

Among these solutes phosphorus (P) is normally found in high concentrations in wastewater, with values ranging from 11 to 22 mg L^{-1} in organic and inorganic forms, and is therefore considered a pollutant of watercourses, causing eutrophication of waters in unpolluted environments by the excessive accumulation of nitrogen (N) and P [8]. On the other hand, in the semiarid region, P is often the most limiting nutrient for agricultural productivity, due to the low levels found in the soil, around 3 mg kg^{-1} [9], a fact that, coupled with low water availability limit biomass production. Although manure fertilization is a common practice in the region, studies have shown the vertical transport of P in sandy soils [10].

In this sense, the objective was to evaluate the effect of treated wastewater application on the recovery of soil organic matter and phosphorus contents in an Anthroposol in a semiarid region.

2. METHODOLOGY

2.1 Description of the Study Area

The study was conducted in an experimental area located near the headquarters of the National Institute of Semiarid (INSA) in Campina Grande, PB, Brazil, located on coordinates 7º15'11"S and 35º56'49"W and about 556 m above the mean sea level. The area dimensions were 60 m wide by 60 m long, totaling 3,600 m^2.

The region is characterized by a hot and humid climate with irregular rainfall and long drought period classified as As' according to the Köeppen classification. The air temperature varies between the annual maximum of 28.6ºC and the minimum of 19.5ºC and the relative humidity with average around 80%.

The relief of the study area is gently undulating, soil corresponding to a Planosol in the classification of Brazil [11] with history of use as a borrowing area for soil removal, was classified as Decapitic Anthroposol according to the proposal of Curcio et al. [12].

Currently the area has been cultivated with the forest species: Aroeira (*Astronium urundeuva Allmanha* Engl.), Brauna (*Schinopsis brasiliensis* Engl.), Catingueira (*Caesalpinia pyramidalis* Tul), Freijó (*Cordia trichotom* Vell), Ipê roxo (*Handroanthus impetiginosus* Mart).

2.2 Wastewater Characterization

The wastewater used for the irrigation of the experiment was obtained from a treatment plant that treats sewage from bathrooms and the kitchen of INSA. Chemical analysis was performed on the water samples included for pH, electrical conductivity, nitrogen, phosphorus, potassium, calcium, magnesium and sodium according to standard wastewater methodology [13].

2.3 Experimental Design

The experiment was conducted in a randomized block design in a split plot scheme, consisting of

Table 1. Chemical and physical attributes from a decapitic anthosoil in Brazilian semiarid region

Chemical attribute			
Attribute		**0 – 15 cm**	**15 – 30 cm**
pH	(H_2O)	5,90	6,00
SOM	(g kg^{-1})	3,01	3,12
N	(g kg^{-1})	0,60	0,50
P	(mg dm^{-3})	2,33	0,65
K	(mg dm^{-3})	54,6	46,8
Ca	($cmol_c kg^{-1}$)	1,52	1,67
Mg	($cmol_c kg^{-1}$)	0,22	0,18
Na	($cmol_c kg^{-1}$)	0,51	0,50
Al	($cmol_c kg^{-1}$)	0,25	0,25
H+Al	($cmol_c kg^{-1}$)	26,4	26,9
Granulometry			
Fraction		0 – 15 cm	15 – 30 cm
Sand	(g kg^{-1})	716	707
Silt	(g kg^{-1})	150	146
Clay	(g kg^{-1})	134	147

SOM, soil organic matter; N, nitrogen; P, phosphorus; K, potassium; Ca, calcium; Mg, magnesium; Na, sodium; Al, aluminum; H + Al, potential acidity

four blocks with five plots corresponding to forest species and three treatments, corresponding to the type and volume of water us ed.

The treatments consisted of three combinations of type and volume of irrigation. Thus, the treatments consisted of 7 L per week of tap water, 7 L per week of treated wastewater and 14 L per week of treated wastewater. In all treatments irrigation was performed by drip located 10 cm away from the stem of the plants.

2.4 Soil Characterization

Soil sampling was carried out with the help of a digger, as it is a very rocky area. For the initial chemical and physical characterization of the area, 80 sampling points were defined and soil samples were taken in the 0-15 and 15-30 cm layers in 2012, before the implementation of the treatments. The collected soil was dried and sieved in 2 mm mesh and analyzed for chemical attributes: pH, nitrogen, phosphorus, potassium, calcium, magnesium, sodium, aluminum and potential acidity (H + Al) (Table 1) according to [14] and soil organic matter (SOM) by the muffle ignition method at 550ºC [15], and granulometry (Table 1).

Two years after the implementation of the treatments, a new soil sampling was performed following the same procedure adopted in the initial sampling. In which 10 points were collected in each row corresponding to the treatments, taking soil samples at two depths, 0 to 15 cm and 15 to 30 cm, 30 cm from the plant stem, totaling 30 points per block.

The collected soil was dried and sieved in 2 mm mesh and analyzed by the same methods as the initial characterization.

2.5 Statistical Analysis

Data were subjected to analysis of variance by the F test and means compared by orthogonal contrasts at the maximum significance level of 0.05 probability using the R statistical package [16]. Then, principal component analysis (PCA) was performed to verify the interrelationships between chemical attributes in the evaluated treatments and in the initial soil condition.

3. RESULTS AND DISCUSSION

3.1 Water Quality and Nutrient Input to Soil

The chemical characterization of the tap water and wastewater used in the experiment is shown in Table 2. It can be observed that from the point of view of the suitability of the water for use in irrigation, both water sources presented some degree of restriction on use. The salinity of both water sources was classified as slight to moderate according to Ayers [17], which means the EC between 0.7 and 3.0 dS m^{-1}. However, it is noteworthy that this classification does not correspond to specific conditions of degraded soils in Brazilian semiarid region but it can be used under these conditions as a parameter to manage the risk of soil contamination.

The pH of both types of water used presented normal range, equivalent to pH between 6.5 and 8.4 (Table 2). In this pH range the concentrations of H^+ and OH^- contained in irrigation waters exerts less influence on nutrient availability and absorption by plants, soil properties and irrigation systems.

Regarding the toxicity of specific ions, the sodium concentration was not restricted for use in either type of water. In both, the concentration of this element was lower than the 69 mg L^{-1} value, by which the water would already have degree of restriction for irrigation. The chloride concentration in both presented mild to moderate degree of restriction, corresponding to chlorine contents between 142 and 355 mg L^{-1}, above 106 mg L^{-1} that characterizes the restriction.

The input of nutrients in the soil applied via wastewater irrigation (Table 3) was higher than the tap water, due to the higher nutrient levels present in it, as shown in Table 4. It is noteworthy that the composition and type of treated wastewater are determinant factors for the supply of significant amounts of nutrients by irrigation.

3.2 Effect on Soil Chemical Attributes

The soil pH did not differ between the irrigated treatments with tap water and wastewater when using the 7 L week^{-1} slide. However, when using the 14 L week-^{1} slide wastewater there was a significant difference ($p < 0.05$) with lower values in this treatment (Table 4). In relation to the initial condition, this treatment provided slight acidification of the soil by the pH reduction, while the treatment with tap water significantly increased the pH values at both depths evaluated.

Irrigation with wastewater provided a significant increase ($p < 0.05$) in organic matter and phosphorus contents in all evaluated layers compared to irrigation with tap water. At a depth of 0-15 cm, the soil organic matter content when applying a 14 L slide were up to 5 times higher than the tap water and at a depth of 15-30 cm this difference was even greater, with values up to 8 times higher.

Increasing SOM content increases the retention and storage capacity of water and nutrients such as P and N. It also increases the cation exchange capacity that assists in the retention of K, Ca and Mg. Although organic matter contained in domestic wastewater generally presents relatively low concentrations, with frequent irrigation, large amounts of SOM occur [5]. These authors reported the influence of SOM on soil physical properties as well, including aggregate structure and stability, aeration, drainage and water retention.

P Mehlich-1 contents in the 0-15 cm layer when irrigated with wastewater were up to 4 times higher than the tap water. In the 15 - 30 layer the difference was smaller, but still 3 times higher than tap water. Regarding organic P levels, the difference was even greater between treatments, in the order of 6 to 8 times higher in the soil irrigated with 14 L of wastewater. Irrigation with tap water only reduced P contents at both depths, provided by the low content of these nutrients in AA.

Significant increases in P levels after application of RA were also observed by other authors who studied the chemical characteristics of cultivated soils irrigated with wastewater [8]. It is important to highlight the occurrence of the increase of P contents in the subsurface layer, where the average values observed in the initial sampling exceeded 0.65 mg kg^{-1}.

Up to 4.61 mg kg^{-1} in the 15 to 30 cm deep layer after wastewater application. This condition was not expected, since P is considered a relatively immobile anion in soils and interacts with the solid phase forming precipitates with Ca, Fe and Al, decreasing its mobility, especially in soils with high clay content [18].

The vertical displacement of P in sandy soils has been reported in the literature [6]. In cases where the source of P is a liquid fertilizer it is found in higher quantities than when applied in solid form. The increase in the concentration of this nutrient in subsurface layers has been reported in sandy soils up to 50 cm deep in leach columns [19].

Due to the lower P adsorption capacity in sandy soils, there is a higher vertical P transport, considered non-existent in clay soils, due to its high affinity for soil colloids. Thus, in sandy soils the P contribution in the soil via wastewater irrigation provides the increase of available P concentrations, both in surface and subsurface layers.

Table 2. Chemical characterization of tap water and treated wastewater used for irrigation of experimental area

Attribute		Water supply	
		Tap water	Wastewater
pH	-	7,5	8,3
EC	dS m^{-1}	0,79	1,35
TOC	mg L^{-1}	1,72	3,7
N	mg L^{-1}	0,28	26,3
NH_4^+	mg L^{-1}	-	22,3
NO_2^-	mg L^{-1}	-	4,5
P	mg L^{-1}	1,68	14
PO_4^{3-}	mg L^{-1}	-	9,4
K^+	mg L^{-1}	5,4	27,6
Ca^{+2}	mg L^{-1}	11,2	24,5
Mg^{+2}	mg L^{-1}	6,4	10,7
SO_4^{3-}	mg L^{-1}	-	51,9
Na^+	mg L^{-1}	9,1	22,3
Cl^-	mg L^{-1}	178	270
RAS	mmol L^{-1}	3,06	5,31

EC, electrical conductivity; TOC, total organic carbon; N, nitrogen; NH_4^+, ammonium; NO_2^-, nitrite; P, phosphorus; PO_4^{3-}, phosphate; K+, potassium, Ca^{+2}, calcium; Mg^{+2}, magnesium; SO_4^{3-}, sulfate; Na+, sodium; Cl-, chlorine; RAS, sodium adsorption ratio

Table 3. Nutrient inputs to the soil from irrigation with two water supply

Attribute		Treatment		
		TW	WW_7	WW_{14}
SOM	g m^{-3}	20,2	65,7	131
N	g m^{-3}	2,90	270	541
P	g m^{-3}	17,3	144	288
K^+	g m^{-3}	55,6	284	568
Ca^{+2}	g m^{-3}	115	252	504
Mg^{+2}	g m^{-3}	65,9	110	220
Na^+	g m^{-3}	93,7	229	459

SOM, soil organic matter; N, nitrogen; P, phosphorus; K, potassium; Ca, calcium; Mg, magnesium; Na, sodium, TW, tap water; WW, wastewater

Table 4. Analysis of variance and mean test for chemical attributes in a degraded soil irrigated with tap water and wastewater in semiarid region

Attribute	Initial condition	Treatments		
		TW	WW7	WW14
0 – 15 cm				
pH	5,87b	6,11a	5,98a	5,58b
SOM	3,01c	2,66c	7,84b	14,66a
P	2,33c	2,32c	4,82b	9,48a
PO	9,28c	6,64c	19,23b	36,66a
15 – 30 cm				
pH	6,03a	3,12c	0,65c	4,02c
SOM	6,21a	1,37d	1,57c	3,43c
P	6,04a	6,26b	2,93b	15,6b
PO	5,66b	11,3a	4,61a	28,2a

pH, hydrogen potential; SOM, soil organic matter; P, phosphorus; PO, organic phosphorus. TW, 7 L per week of tap water; WW7.7 L per week of treated wastewater; WW14, 14 L per week of treated wastewater; Means followed by the same letter on the line are not statistically different from each other by ANOVA followed by Tukey test at 5% probability level

Therefore, the increase in phosphorus levels found in the present study is certainly associated with the sandy soil texture, which allowed the vertical movement of the adsorbed P applied to the superficial layer to the subsurface layers. The soil's ability to retain P contributes to preventing P leaching below the root zone and may determine the sustainability of crops where wastewater is used for irrigation. However, in the application of wastewater to soil, P is assumed to be highly retained in soil, but studies have shown an increase in P concentration in the deepest layers, although often these increases in P in solution are of little significance.

4. CONCLUSION

The irrigation with treated wastewater increased soil organic matter and phosphorus content to a depth of 30 cm.

Under the conditions in which the study was conducted, the use of wastewater proved to be a promising alternative for the recovery of soil production capacity by increasing soil organic matter and phosphorus levels.

Although there are few studies published on wastewater reuse in semiarid regions, it can effectively be considered a short-term alternative for the recovery of degraded areas due to nutrient and organic matter inputs to the soil.

This still is an area of study that needs the attention of researchers in order to reduce water scarcity and promote the reuse of domestic effluents in to avoid soil contamination and promote the recovery of the productive capacity of degraded soils in the semiarid regions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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