

Original Research Article

Potential of wastewater reuse in soil fertility recovery in a semiarid region

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 water. 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 than application of tap water in the superficial layer and 8 times higher in the sub-surface, respectively. From the results found, we can considered that the use of wastewater from treated domestic sewage can be considered 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.

Keywords: phosphorus, soil organic matter, water reuse

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. 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 [1] 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 [2].

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 [3, 4]

Although the use of these waters presents 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 [5, 6, 7].

Comment [G1]: Do you mean to talk about 7 and 14 L of wastewater ?

Comment [G2]: Was it five times higher ? Please specify

Comment [G3]: obtained

Comment [G4]: it can be

Comment [G5]: serve as

Comment [G6]: water sources

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

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

48 2. METHODOLOGY

49 2.1 Description of the Study Area

52 The study was conducted in an experimental area located near the headquarters of the
53 National Institute of Semiarid (INSA) in Campina Grande, PB, with dimensions of 60 m wide
54 by 60 m long, totaling 3,600 m².

Comment [G7]: It is important to specify the country i.e. Brazil. This will help situate the reader.

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

59 The relief of the study area is soft undulating, soil corresponding to a Planosol in the
60 classification of [11] with history of use as a borrowing area for soil removal, was classified
61 as Decapitic Anthrosol according to the proposal of [12].

Comment [G8]: gently

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

65 2.2 Wastewater characterization

66 The wastewater used for the irrigation of the experiment was obtained from a treatment plant
67 that treats sewage from bathrooms and the kitchen of INSA. In which characterization was
68 performed chemistry for pH, electrical conductivity, nitrogen, phosphorus, potassium,
69 calcium, magnesium and sodium according to standard wastewater methodology [13].

Comment [G9]: Chemical analyses performed on the water samples included

70 2.3 Experimental Design

71 The experiment was conducted in a randomized block design in a split plot scheme,
72 consisting of four blocks with five plots corresponding to forest species and three treatments,
73 corresponding to the type and volume of water used.

74 The treatments consisted of three combinations of type and volume of irrigation. Thus, the
75 treatments consisted of 7 L per week of tap water, 7 L per week of treated wastewater and
76 14 L per week of treated wastewater. In all treatments irrigation was performed by drip
77 located 10 cm away from the stem of the plants.
78

79 2.4 Soil Characterization

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

Comment [G10]: Why not SOM?

87 **Table 1.** Chemical and physical attributes from a Decapitic Anthosol in Brazilian semiarid
88 region.

Chemical attribute			
Attribute		0 – 15 cm	15 – 30 cm
pH	(H ₂ O)	5,90	6,00
MO	(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

Comment [G11]: OM

89 MO, organic matter; N, nitrogen; P, phosphorus; K, potassium; Ca, calcium; Mg, magnesium; Na, sodium; Al,
90 aluminum; H + Al, potential acidity.

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

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

97

98 2.5 Statistical analysis

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

104 **3. RESULTS AND DISCUSSION**

105
106 **3.1 Water Quality and nutrient input to soil**

107 The chemical characterization of the tap water and wastewater used in the experiment is
108 shown in table 2. It can be observed that from the point of view of the suitability of the waters
109 for use in irrigation, both waters presented restriction of use regarding the related problems.
110 salinity, varying from mild to moderate, as it has EC between 0.7 and 3.0 dS m⁻¹ according
111 to [17]. However, it is noteworthy that this classification does not correspond to specific
112 conditions of degraded soils in semiarid region, ~~however it can be used under these~~
113 conditions as a parameter to manage the risk of soil contamination.

Comment [G12]: Please rewrite this sentence. It is not clear.

Comment [G13]: and

114
115 **Table 2.** Chemical characterization of tap water and treated wastewater used for irrigation of
116 experimental area

Attribute	Water supply	
	Tap water	Wastewater
pH	-	7,5
CE	dS m ⁻¹	0,79
TOC	mg L ⁻¹	1,72
N	mg L ⁻¹	0,28
NH ₄ ⁺	mg L ⁻¹	-
NO ₂ ³⁻	mg L ⁻¹	-
P	mg L ⁻¹	1,68
PO ₄ ³⁻	mg L ⁻¹	-
K ⁺	mg L ⁻¹	5,4
Ca ⁺²	mg L ⁻¹	11,2
Mg ⁺²	mg L ⁻¹	6,4
SO ₄ ³⁻	mg L ⁻¹	-
Na ⁺	mg L ⁻¹	9,1
Cl ⁻	mg L ⁻¹	178
RAS	mmol L ⁻¹	3,06
		5,31

Comment [G14]: EC

Comment [G15]: Please check this formula for nitrite ion. Is it NO₂⁻?

117 EC, electrical conductivity; TOC, total organic carbon; N, nitrogen; NH₄⁺, ammonium; NO₂³⁻, nitrite; P, phosphorus;
118 PO₄³⁻, phosphate; K⁺, potassium; Ca⁺², calcium; Mg⁺², magnesium; SO₄²⁻, sulfate; Na⁺, sodium; Cl⁻, chlorine; RAS,
119 sodium adsorption ratio.

Comment [G16]: Please check this

120
121 The pH of both types of water used presented normal range, equivalent to pH between 6.5
122 and 8.4 (Table 2). In this pH range the concentrations of H⁺ and OH⁻ contained in irrigation
123 waters exerts less influence on nutrient availability and absorption by plants, soil properties
124 and irrigation systems.

125
126 Regarding the toxicity of specific ions, the sodium concentration was not restricted for use in
127 either type of water. In both, the concentration of this element was lower than the 69 mg L⁻¹
128 value, by which the water would already have degree of restriction for irrigation. The chloride
129 concentration in both presented mild to moderate degree of restriction, corresponding to
130 chlorine contents between 142 and 355 mg L⁻¹, above 106 mg L⁻¹ that characterizes the
131 restriction.

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

136
137

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

Attribute		Treatment		
		TW	WW ₇	WW ₁₄
MO	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

Comment [G17]: OM

138 MO, organic matter; N, nitrogen; P, phosphorus; K, potassium; Ca, calcium; Mg, magnesium; Na, sodium, TW, tap
139 water; WW, wastewater.

Comment [G18]: OM

140
141

3.2 Effect on soil chemical attributes

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

148 **Table 4.** Orthogonal contrasts of chemical attributes in a degraded soil irrigated with tap
149 water and wastewater in semiarid region.

Attribute	TW;WW7	Treatments	
		TW;WW14	WW7;WW14
0 – 15 cm			
pH	6,11;5,98 ^{ns}	6,11;5,58 [*]	5,98;5,58 [*]
MO	2,66;7,84 [*]	2,66;14,66 ^{**}	7,84;14,66 ^{**}
P	2,32;4,82 ^{**}	2,32;9,48 ^{**}	4,82;9,48 ^{**}
PO	6,64;19,23 [*]	6,62;36,66 ^{**}	19,23;36,66 ^{**}
15 – 30 cm			
pH	6,11;6,04 ^{ns}	6,11;5,66 [*]	6,04;5,66 [*]
MO	1,37;6,26 ^{**}	1,37;11,29 ^{**}	6,26;11,29 [*]
P	1,57;2,93 [*]	1,57;4,60 ^{**}	2,93;4,60 [*]
PO	3,43;15,65 [*]	3,43;28,21 ^{**}	15,65;28,21 [*]

Comment [G19]: OM

Comment [G20]: OM

150 pH, hydrogen potential; MO, organic matter; P, phosphorus; PO, organic phosphorus. TW, 7 L per week of tap
151 water; WW7, 7 L per week of treated wastewater; WW14, 14 L per week of treated wastewater; ns: not significant, **
152 significant at 1%, * significant at 5%.

Comment [G21]:

153 Irrigation with wastewater provided a significant increase (p <0.05) in organic matter and
154 phosphorus contents in all evaluated layers compared to irrigation with tap water (Table 4).
155 At a depth of 0 - 15 cm, the soil organic matter content when applying a 14 L slide were up
156 to 5 times higher than the tap water and at a depth of 15 - 30 cm this difference was even
157 greater, with values up to 8 times higher.

Comment [G22]: SOM

158 Increasing MOS content increases the retention and storage capacity of water and nutrients
159 such as P and N. It also increases the cation exchange capacity that assists in the retention
160 of K, Ca and Mg. Although organic matter contained in domestic wastewater generally
161 presents relatively low concentrations, with frequent irrigation, large amounts of MOS occur

Comment [G23]: SOM

162 [5]. These authors reported the influence of MOS on soil physical properties as well,
163 including aggregate structure and stability, aeration, drainage and water retention.

Comment [G24]: SOM

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

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

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

178 In this sense, the vertical displacement of P in sandy to sandy loam soils has been reported
179 in the literature [6]. In cases where the source of P is a liquid fertilizer or when applied with
180 drip fertigation and several times higher than when applied to soil in solid form. The increase
181 in the concentration of this nutrient in subsurface layers has been reported in sandy soils up
182 to 50 cm deep in leach columns [19].

Comment [G25]: This sentence is not clear.
Please rewrite it.

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

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

195 4. CONCLUSION

196
197 Irrigation with treated wastewater can increase soil organic matter and phosphorus content
198 to a depth of 30 cm.

199 By promoting the increase of soil organic matter and phosphorus contents, the use of treated
200 wastewater can be considered an alternative for the recovery of the productive capacity of
201 degraded soils in the semiarid region.

202

203 **COMPETING INTERESTS**

204

205 Authors have stated that there are no competitors.

206

207

208

209

REFERENCES

210

211

212

213

214

1. DOETTERL S, BERHE, AA, SWIM AND, WANG Z, SOMMER Z; FIENER P. Erosion, deposition and soil carbon: A review of process-level controls, experimental tools and models to address C cycling in dynamic landscapes. *Earth-Science Reviews*, 2016; 145: 102-122.

215

216

217

2. SANTOS, L. M. S; TAVARES, V. M. M; MEYER, M. F. Environmental, technical and economic feasibility evaluation of gravel extraction activity in the municipality of Arês - RN. *Technical Scientific Congress of Engineering and Agronomy*. 2015

218

219

220

3. BECERRA-CASTRO, C. et al. Wastewater reuse in irrigation: A microbiological perspective on implications in soil fertility and human and environmental health. *Environment International*, v. 75, p. 117–135, 2015.

221

222

223

4. BONINI, C. S. B .; ALVES, M. C .; MONTANARI, R. Sewage sludge and mineral fertilization in the recovery of chemical attributes of degraded soil. *Brazilian Journal of Agricultural and Environmental Engineering*, p. 388–393, 2015.

224

225

226

227

5. MEDEIROS, S.S .; SOARES, A.A .; FERREIRA, P.A .; SOUZA, J.A.A .; SOUZA, J.A .; MATOS, A.T. Behavior of soil chemical attributes in response to domestic wastewater application. *Brazilian Journal of Agricultural and Environmental Engineering*, Campina Grande, PB, v.9, (Supplement), p.268-273, 2005.

228

229

230

231

6. ANAMI, M. H .; SAMPAIO, S. C .; SUSZEK, M .; GOMES, S. D .; QUEIROZ, M. M. F. Miscible displacement of nitrate and phosphate from swine wastewater in soil columns. *Brazilian Journal of Agricultural and Environmental Engineering*, v.12, p.75-80, 2008.

232

233

234

235

7. CARVALHO, R. S .; SANTOS FILHO, J. S .; SANTANA, L. O. G.; GOMES, D. A .; MENDONÇA, L. C .; FACCIOLI, G. G. Influence of wastewater reuse on the microbiological quality of sunflower for animal feed. *Ambi-Agua*, Taubate, v. 8, no. 2, p. 157-167, 2013.

236

237

238

8. KLEIN, C .; AGNE, S. A. A. Phosphorus: from nutrient to pollutant! *Electronic Journal on Environmental Management, Education and Technology*, v.8, No. 8, p. 1713-1721, Sep-Dec, 2012.

239

240

241

242

9. SALCEDO, I.H. & SAMPAIO, E.V.S.B. Soil organic matter in the Caatinga biome. In: SANTOS, G.A .; SILVA, L.S .; CANELLAS, L.P. & CAMARGO, F.A.O., eds. *Fundamentals of soil organic matter: Tropical and subtropical ecosystems*. 2.ed. Porto Alegre, Metropolis, 2008. p.419-441.

243

244

245

10. GALVÃO, S. R. S; SALCEDO, I. H. Soil Phosphorus Fractions in Sandy Soils Amended with Cattle Manure for Long Periods. *Brazilian Journal of Soil Science*, v. 33, p.613-622, 2009.

- 246 11. BRAZIL. Ministry of Agriculture. Exploratory and Soil Recognition Survey of Paraíba
247 State. Bulletin 15, Pedology Series, 8, Rio de Janeiro: 1972.
- 248 12. CURCIO, G. R. ; LIMA, V. C. ; GIAROLA, N. F. B. Anthrosols: Order proposal (1st
249 approximation). Colombo: EMBRAPA Forests, 2004.
- 250 13. APHA, 2012. Standard Methods for Examining Water and Wastewater, 22nd edition
251 edited by E.W. Rice, R.B. Baird, A.D. Eaton and L.S. Clesceri. American Public
252 Health Association (APHA), American Water Works Association (AWWA) and Water
253 Environment Federation (WEF), Washington, D.C., USA, 2012.
- 254 14. TEIXEIRA, P. C; DONAGEMMA, G. K; FONTANA, A; TEIXEIRA, W. G. Manual of
255 soil analysis methods. 3 ed. Brasilia, 2017, 573p.
- 256 15. SCHULTE, E.E. ; J.B. PETERS; P. HODGSON. Wisconsin Procedures for soil
257 testing, plant analysis and fud & forage analysis. Department of soil science.
258 University of Wisconsin-Extension, Madison, WI, 1987. 9p.
- 259 16. R CORE TEAM (2018). A: The language and environment for statistical computing.
260 R Foundation for Statistical Computing, Vienna, Austria. Available at: <[http://www.R-
261 project.org/](http://www.R-project.org/)>.
- 262 17. AYERS, R.S. ; WESTCOT, D.W. Water quality in agriculture. Campina Grande:
263 Federal University of Paraíba, 153p, 1999.
- 264 18. OLATUYI, S. O. ; AKINREMI, O. O. ; FLATEN, D. N. & CROW, G. H. Accompanying
265 cations and anions affect the diffusive transport of phosphate in the model
266 calcareous soil system. Canadian Journal of Soil Science, v. 89, p. 179-188, 2009.
- 267 19. AZEVEDO, R. P; SALCEDO, I. H; LIMA, P.A; FRAGA, V. S; LANA, R. M. Q. Mobility
268 of phosphorus from organic and inorganic source materials in a sandy soil.
269 International Journal of Recycling of Organic Waste In Agriculture, v. 7, p. 153-163,
270 2018.
- 271 20. FALKINER, R. A. ; SMITH, C.J. Changes in soil chemistry in effluent-irrigated *Pinus*
272 *radiata* and *Eucalyptus grandis*. Australian J. Soil Research, v.35, p.131-147, 1997.