

*Full Length Research Paper*

# Soil Chemical Characteristics Under Color Cotton Cultivation with Wastewater Irrigation in Brazil's Arid Climate

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Research found the effect of treated wastewater on chemical properties of the soil cultivated with cotton. The soil fertility was studied by using a randomized blocks experimental design in factorial scheme (4 x 2) with three replications, whose factors were four treated wastewater depths (278, 416, 554 and 692 mm) and two soil sampling times (before and after cultivation of colored cotton, with a rainfall of 89 mm during the crop cycle); while for the soil salinity, it was also used the experimental design in randomized blocks, but in factorial scheme (4 x 3) with three repetitions, being the factors the same four treated wastewater depths used in the fertility study, and three times of soil sampling (before and after the irrigation and after the rainfall period). After irrigation with effluent of stabilization pond and a rainfall of 89 mm, the contents of P, K<sup>+</sup>, Ca<sup>2+</sup>, H<sup>+</sup> and the capacity of cationic change of the soil increased, while the contents of Na<sup>+</sup>, Mg<sup>2+</sup> and the sodium exchangeable percentage decreased. However, the electrical conductivity, the sodium adsorption ratio and the contents of calcium, magnesium, sodium, chlorides of the soil saturation extract decreased after five months of rains, which totalized 646 mm.

**Key words:** Reuse, irrigation, soil.

## INTRODUCTION

The urban domestic wastewater reuse aiming fertirrigation industrial crops as cotton is considered an alternative use and final disposition of this appeal and, at

the same time, a way to increase the productivity of crops in fertirrigation areas, given the presence of nutrients as Ca<sup>2+</sup>, Mg<sup>2+</sup>, N, P, K<sup>+</sup>, and S, and micronutrients in their

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chemical composition. However, it is unknown that the antagonistic effects of its implementation on the chemical characteristics of the soil, as well as the chemical characteristics that the soil will pass with the effects of seasonality.

Mapanda et al. (2005), study the effect of long-term irrigation using wastewater on heavy metal contents of soils under vegetables, found that the magnitude of contamination, regulatory compliance and annual loadings of soils with copper (Cu), zinc (Zn), cadmium (Cd), nickel (Ni), chromium (Cr) and lead (Pb) where wastewater was used to irrigate vegetable gardens for at least 10 years. According to these authors, the annual heavy metal loading rates showed that within 5 to 60 years, all studied heavy metals would have exceeded their permitted limits in soils, depending on site. It was concluded that the use of wastewater in urban horticulture enriched soils with heavy metals to concentrations that may pose potential environmental and health risks in the long-term. Soils, as filters of toxic chemicals, may adsorb and retain heavy metals from wastewater. But when the capacity of soils to retain toxic metals is reduced due to continuous loading of pollutants or changes in pH, soils can release heavy metals into groundwater or soil solution available for plant uptake (Mapanda et al., 2005). Kimberly and William (1999), report that the amount of heavy metals mobilized in a soil environment is a function of pH, clay content, organic matter content, cation exchange capacity and other soil properties making each soil unique in terms of pollution management.

While Smith (1996) reports that with the exception of Mo, Se and As, heavy metal mobility decreases with increasing soil pH due to precipitation of hydroxides, carbonates or formation of insoluble organic complexes. The idea of reuse has been developing to turn an integral factor of preservation and rational use of water resources, besides being an important practice for semi-arid areas as the one of the Brazilian northeast, representing a form of water supply for irrigation and sources of minerals nutrients and organic composed (Arthur, 1983).

According to Jnad et al. (2001), the significant increase of the amount of  $\text{Na}^+$  and P in the soil was the main alterations in the chemical characteristics of the soil, resulting from application of wastewater of domestic origin, through underground drip irrigation system, in areas cultivated with gram. However, significant increases were not observed in the amounts of total-N,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ , and electrical conductivity of the extract of soil saturated paste. In the work of Speir et al. (1999), although the content of  $\text{Na}^+$  has increased by application of secondary effluents of treated sewer, the inverse happened when the irrigation ceased, due to the effect of rainfalls on lixiviation of that cation. In the work of Day et al. (1979), the irrigation with effluent of treated sewer did not alter the pH of the soil. However, in this situation, the

soil was from a semi-arid area naturally alkaline. However, in work of Sou/Dakouré et al. (2013), found that plots irrigated with wastewater showed important structural damages, especially in the subsurface horizon where the soil pore network collapsed dramatically, resulting in a compact impermeable layer. Fluorescence spectra revealed that the organic matter contained in the wastewater was largely dissolved due to a sharp soil pH increase, resulting in black alkali formation at the surface; the soil became sodic, with an exchange complex dominated by sodium, whereas plots irrigated with fresh water kept properties comparable to that of non irrigated plots. Such a rapid soil sodication was seldom reported so far.

The authors emphasizes the need to carefully examine irrigation water quality and particularly calcite residual alkalinity and suggests that shrinkage analysis could be used to monitor the physical changes of soil properties upon sodication. Inadequate wastewater quality is likely to cause deep and irreversible damages to irrigated soils.

Christou et al. (2014), study the assessment of long-term wastewater irrigation impacts on the soil geochemical properties and the bioaccumulation of heavy metals to the agricultural products, found that the heavy metal content quantified in the forage plants' above-ground parts was below the critical levels of phytotoxicity and the maximum acceptable concentration in dairy feed, whereas heavy metals quantified in orange fruit pulp were below the maximum permissible levels (MPLs), and that heavy metal phyto availability was confined due to soil properties (high pH and clay content), as evidenced by the calculated low transfer factor (TF).

On the other hand, Vazquez et al. (1996) verified decrease of the pH in soil cultivated with corn and irrigated with effluent of treated sewer. The authors suggested that the fall in the pH of the soil was due to nitrification, once that effect was increased by addition of nitrogen mineral fertilizer. According to Pizarro (1990), the soluble salts contained in the irrigation waters can, in certain climatic conditions, generate salt problems in the soil and to modify the ionic composition in the sorption compound, altering the physical and chemical characteristics of the soil, as the humidity regime, aeration, nutritious, vegetative development and productivity.

Normally the rate of potential nitrification presents temporal variation, or better, a close relationship between the concentration of  $\text{NO}_3^-$  and rainfall. Thus, during the dry period, there is low rate of mineralization, however, with the onset of rains, the increased rate of mineralization of organic matter provides greater release of  $\text{NH}_4^+$ , substrate of nitrification and, consequently, increased in concentration of  $\text{NO}_3^-$  in soil (Wheatley et al., 2001). The objective of this study was to verify the effect of irrigation with different treated wastewater depths on some chemical attributes of the soil at the end of irrigation and rainfall seasons.



**Table 1.** Variance analyses of chemical attributes of the soil for different wastewater depths (W) and soil sampling time (T).

Sources of variation	DF	Mean squares							
		P	K <sup>+</sup>	Na <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	H <sup>+</sup>	CCC	PES
W	3	10.61 <sup>**</sup>	2007.3 <sup>**</sup>	1.873 <sup>*</sup>	43.62 <sup>ns</sup>	13.70 <sup>ns</sup>	0.527 <sup>ns</sup>	10.62 <sup>ns</sup>	2.544 <sup>ns</sup>
T	1	422.5 <sup>**</sup>	21716.5 <sup>**</sup>	176.3 <sup>**</sup>	50.86 <sup>ns</sup>	90.28 <sup>*</sup>	264.2 <sup>**</sup>	21.31 <sup>ns</sup>	290.9 <sup>**</sup>
W x T	3	1.610 <sup>ns</sup>	426.4 <sup>ns</sup>	4.122 <sup>**</sup>	3.26 <sup>ns</sup>	3.438 <sup>ns</sup>	3.098 <sup>ns</sup>	13.43 <sup>ns</sup>	5.598 <sup>*</sup>
Blocks	2	45.76 <sup>**</sup>	6944.1 <sup>**</sup>	5.114 <sup>**</sup>	11.78 <sup>ns</sup>	5.687 <sup>ns</sup>	97.53 <sup>**</sup>	130.60 <sup>ns</sup>	4.144 <sup>*</sup>
Residue	14	1.748	310.2	0.375	35.23	10.55	1.529	52.78	1.053
Total	23								
C.V (%)		14.70	14.66	11.58	13.86	23.81	8.25	9.11	15.35

\*, \*\*, ns - Significant, respectively, for 5% and 1% and no significant by the Test F. DF – degrees of freedom.

## MATERIALS AND METHODS

This research was developed under field conditions, in the Station of Sewer Treatment of the Company of Water and Sewer of Paraíba state, Campina Grande city, Brazil, in an area irrigated with wastewater cultivated with colored cotton. The soil of the area was a sandy-clay-loam with contents of sand, silty and clay of 62.9, 16.11 and 20.98%, respectively, and content of organic matter of 7.7 g kg<sup>-1</sup> and percentage of exchangeable sodium of 4.28%. The humidity at field capacity and at wilting point was, respectively, 124.7 and 45.3 g kg<sup>-1</sup>. For the fertility analysis it was used the experimental design randomized blocks in factorial scheme (4 x 2), with three replications, whose factors were four irrigation water depths (692, 554, 416 and 278 mm) and two times of soil collection (before and after cultivation of cotton, with a rainfall of 89 mm during the crop cycle), while for salinity, it was used also an experimental design in randomized blocks, but in factorial scheme (4 x 3), with three replications, whose factors were four irrigation water depths (692, 554, 416 and 278 mm) and three times of soil collection (before irrigation; after irrigation with a rainfall of 89 mm during the crop cycle; and after the rainy season of 646 mm). The experimental plot consisted of an area of 20 m<sup>2</sup>, and the arrangement of plants was in simple rows with spacing of 0.20 m between plants and 1 m between rows.

The water from the stabilization pond was stored in 2 PVC reservoirs of 5000 L, and a pumping was used for delivering the water up to the drip irrigation system with lateral lines of polyethylene and self compensating emitters spaced 50 cm with discharge of 4 L h<sup>-1</sup>. The water from these two reservoirs passed with a discharge of 10 m<sup>3</sup> h<sup>-1</sup> by a sand filter, a disk filter of 130 micron, and a screen filter of 130 micron.

The effluent of treated domestic sewer had the following characteristics: electrical conductivity of 1.40 dS m<sup>-1</sup>, sodium 109.79 mg L<sup>-1</sup>, maniacal nitrogen 60.5 mg L<sup>-1</sup>, nitrate 3.3 mg L<sup>-1</sup>, potassium 23.01 mg L<sup>-1</sup>, calcium 25 mg L<sup>-1</sup>, magnesium 23.4 mg L<sup>-1</sup>, bicarbonate 195.81 mg L<sup>-1</sup>, chloride 199 mg L<sup>-1</sup>, phosphorus 4.6 mg L<sup>-1</sup>, and soluble orthophosphate 3.2 mg L<sup>-1</sup>. The soil collections were accomplished before and after the cultivation of cotton. After the soil has been dried and drizzled, samples were taken for determining the values of P, K<sup>+</sup>, Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, H<sup>+</sup>, pH, capacity of cationic change (CCC) and percentage of exchangeable sodium (PES), according to methodology recommended by Embrapa (1997). The soil analyses were accomplished in the Laboratory of Chemistry and Fertility of the Soil, belonging to Paraíba Federal University.

## RESULTS AND DISCUSSION

The variance analysis for chemical attributes of the soil

revealed significant effect of the tested wastewater depths on values of P, K<sup>+</sup> and Na<sup>+</sup>; thus, not exercising effect on values of Ca<sup>2+</sup>, Mg<sup>2+</sup>, H<sup>+</sup>, CCC and PES (Table 1). For the times of soil collection the effect was significant only for values of P, K<sup>+</sup>, Na<sup>+</sup> and PES. There was only interaction among the wastewater depths and the soil collection times for Na<sup>+</sup> and PES. Great variation coefficients were obtained for all the appraised variables.

According to Table 2 the mean values of phosphorus, potassium, sodium, calcium, magnesium, hydrogen, CCC and PES of the soil for different wastewater depths (W) and soil sampling time (before and after cultivation – T). It is verified that for the factor soil sampling time the values of P, K<sup>+</sup>, Ca<sup>2+</sup>, H<sup>+</sup> and CCC increased after the irrigation with wastewater. There was decrease of the values of Na<sup>+</sup>, Mg<sup>2+</sup> and of PES after the irrigation and 89 mm of rainfall. The pH before the cultivation varied from 7.03 to 7.19 and after from 6.23 to 6.43. There was elevation of phosphorus contents after the cultivation, certainly due to the contribution through irrigation water; there were not great differences among the water depths, being the content of exchangeable phosphorus in the soil of 11.42 mg dm<sup>-3</sup>. The increase of the contents of calcium caused larger fixation of phosphorus to clay particles.

Usually, the pH of the irrigation water has not been affecting the pH of the soil significantly, because of its power lid; thus, it is not expecting direct effect of the effluent in the pH of the soil, even with the widespread occurrence of HCO<sub>3</sub><sup>-</sup> (one of the present forms of alkalinity) in the wastewaters. However, there is the possibility of that alkalinity associated to high concentrations of Na<sup>+</sup> and CO<sub>3</sub><sup>2-</sup>, in alkaline waters, to cause increase of the value of pH of the soil (Bouwer and Idelovitch, 1987). In soils treated with biodegradable residues (as the sewer effluent), through the degradation of these materials by the microorganisms, it can have decrease in the value of pH of the soil due to the production of CO<sub>2</sub> and organic acids (Bouwer and Chaney, 1974).

Duarte et al. (2008) evaluating the effects of disposal of treated domestic sewage on some chemical characteristics of the soil, found that the used effluent showed physical and chemical quality suitable for irrigation and the use



**Table 2.** Mean values of phosphorus, potassium, sodium, calcium, magnesium, hydrogen, capacity of cationic change (CCC) and percentage of exchangeable sodium (PES) of the soil for different wastewater depths (W) and soil sampling time (before and after cultivation – T).

Factors	Mean values							
	P	K <sup>+</sup>	Na <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	H <sup>+</sup>	CCC	PES
	W (mm)	mg dm <sup>-3</sup>		mmolc dm <sup>-3</sup>			%	
781	8.60	112.06	4.98	44.86	12.52	15.11	80.36	6.28
643	7.37	105.89	5.44	38.95	15.83	15.23	78.17	6.94
505	10.50	146.87	6.01	44.45	12.76	14.55	81.22	7.47
367	9.50	115.60	4.73	43.05	13.46	15.04	79.20	6.04
LSD	2.21	29.56	1.02	9.96	5.45	2.07	12.19	1.72
T								
Before	4.79 <sup>b</sup>	90.02 <sup>b</sup>	8.00 <sup>a</sup>	41.37 <sup>a</sup>	15.58 <sup>a</sup>	11.67 <sup>b</sup>	78.79 <sup>a</sup>	10.16 <sup>a</sup>
After	13.18 <sup>a</sup>	150.1 <sup>a</sup>	2.58 <sup>b</sup>	44.28 <sup>a</sup>	11.70 <sup>b</sup>	18.30 <sup>a</sup>	80.68 <sup>a</sup>	3.20 <sup>b</sup>
LSD	1.15	15.42	0.53	5.19	2.84	1.08	6.36	0.89

Mean values followed by the same letter in the column don't differ amongst themselves, by the test of Tukey to 5% of probability. LSD – least significant difference.

of wastewater favored the rapid mineralization of organic matter as a result of the concentration of carbon and nitrogen existing in these waters. The use of wastewater not caused significant changes at pH, nor in the levels of phosphorus and potassium of the soil.

According to Figure 1, the contents of phosphorus and exchangeable potassium in the soil increased after the cultivation, being attributed that increase to the contribution of these elements through irrigation water (Figure 1a and b). The largest and smallest phosphorus and potassium contents were found, respectively, for treatments with water depths of 505 and 781 mm. The calcium had a light increment after the cultivation, staying in the soil in large contents, in spite of being an element of easy lixiviation (Figure 1c); among the water depths the calcium did not vary so much, which mean value was 44.33 mmolc dm<sup>-3</sup>. However, the magnesium decreased after the cultivation certainly due to rains that easily drag certain amounts of nutrients (Figure 1d). Among the water depths there were not great variations, being its mean value of 11.04 mmolc dm<sup>-3</sup>.

Fonseca (2001) found that the disposal of treated effluent in fertilized soil not exercised any influence on the content of phosphorus, but there was decrease of magnesium, independent of the irrigation water used (potable or treated effluent). Kouraa et al. (2002) watered potato and lettuce with raw sewage, treated wastewater and drinking water and found that in a year of cultivation there's been no change in phosphorus levels in the cultivated soil. The authors reported that to occur changes in soil chemical characteristics are required several years of irrigation, whereas the dynamics of this occurs very slowly; on the other hand, Al-Nakshabandi et al. (1997) contradict the authors mentioned above, because in just five months cultivating Eggplant irrigated with treated effluent containing 28 mg L<sup>-1</sup> of PO<sub>4</sub><sup>-</sup>, there

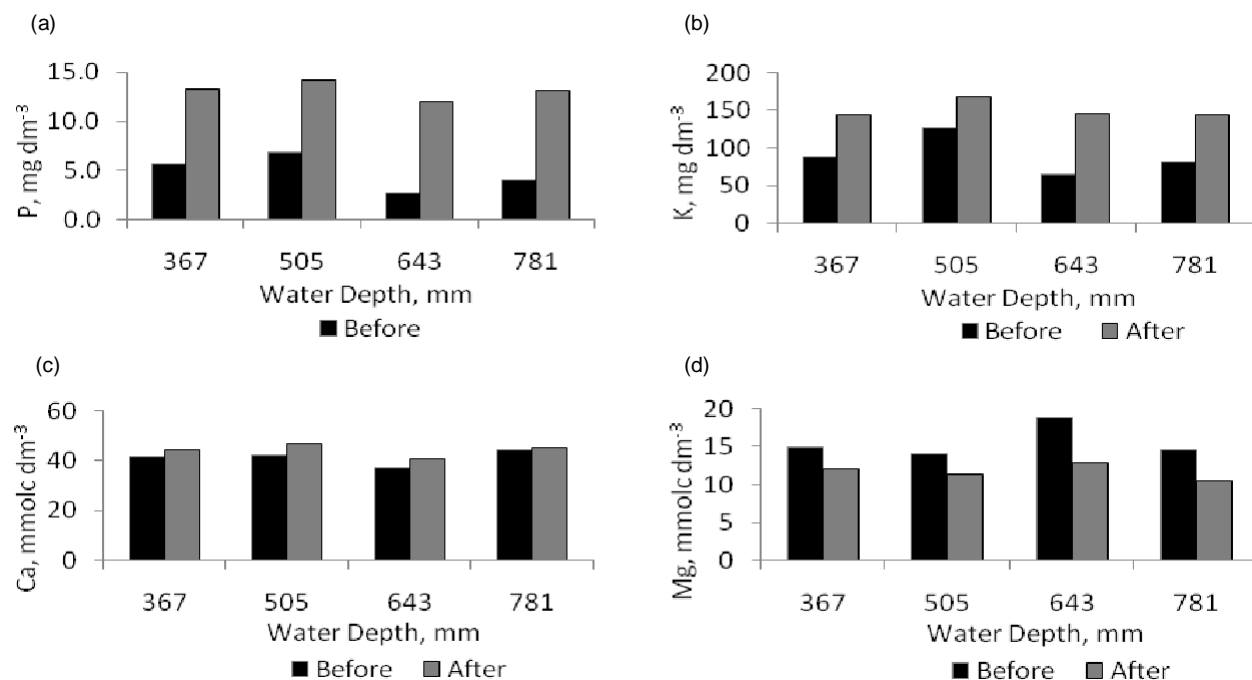
have been significant increase in soil phosphorus levels.

Increases in levels of exchangeable potassium in the soil had been evidenced by Adekalu and Okunade (2002); however, agreeing with the existing conditions in this study, Kouraa et al. (2002), using raw sewage, treated effluent and drinking water for irrigation of potato and lettuce, not found significant differences in the levels of potassium in soil receiving these three types of water. The sodium decreased after the cultivation, certainly once again due to the precipitation of 89 mm happened during the experiment, and also by using a drip irrigation system, which forms a humid bulb in the soil profile, and so the salts contained in the soil or in the irrigation water tend to address for the periphery of the bulb, reducing a lot the contents of salts inside of the humid bulb; there were not great variations among the applied water depths, being the mean value of 2.45 mmolc dm<sup>-3</sup> (Figure 2a).

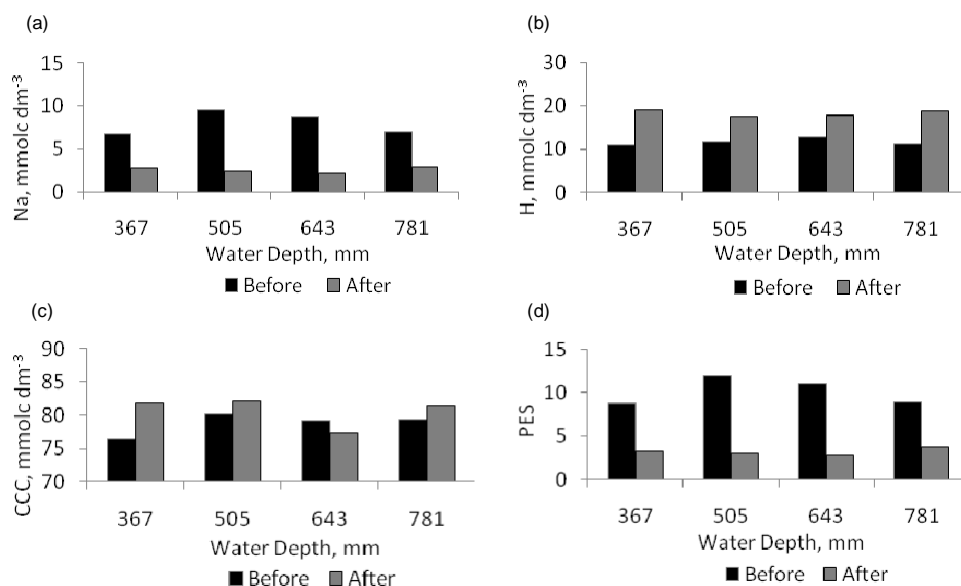
The contents of hydrogen increased after the cultivation, due to microbial activity, which liberates a lot of hydrogen, and also to precipitation that elevates the contents of hydrogen in the soil; however, it is verified that among potassium, calcium and magnesium, the element that was more expressively reduced with the entrance of hydrogen was magnesium (Figure 2b). The capacity of cationic change (CCC) of the soil was already very high before the beginning of irrigation, with a minimum value of 76.49 mmolc dm<sup>-3</sup>; generally, the irrigation with wastewater, which gave a great contribution of nutrients, increased CCC; in relation to water depths, the increase of CCC was larger for 367 mm (Figure 2c). The calculations of the percentage of exchangeable sodium based on CCC decreased after the cultivation, being the reductions larger in water depths of 505 and 643 mm (Figure 2d).

In Table 3 the variance analysis for soil chemical





**Figure 1.** Contents of phosphorus, potassium, calcium and magnesium of the soil, before and after cultivation of cotton irrigated with wastewater.



**Figure 2.** Contents of sodium, hydrogen, capacity of cationic change (CCC) and percentage of exchangeable sodium (PES) of the soil, before and after cultivation of cotton irrigated with wastewater.

attributes reveals significant effect of tested wastewater depths on electrical conductivity of extract of saturation of the soil (EC),  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{HCO}_3^-$ ,  $\text{Cl}^-$ , and sodium adsorption ratio (SAR). The effect was also significant among the times of collection of the soil for all appraised chemical

attributes. There was not interaction of water depths and of soil collection times for EC and for contents of bicarbonate ( $\text{HCO}_3^-$ ).

Cavallet et al. (2006) studying the fertilizer value of wastewater of an industry of enzymes in a Yellow Red



**Table 3.** Variance analyses of chemical attributes and of sodium adsorption ratio (SAR) of the soil for different wastewater depths and times of soil sampling (E), that is, before and after irrigation and after the rainy season.

Sources of Variation	DF	Mean Square							
		EC	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	HCO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	SAR
Water Depths (W)	3	0.144*	0.456*	0.724*	19.13**	0.167**	6.203**	8.611**	2.329**
Times (E)	2	1.075**	1.662**	3.893**	180.0**	1.658**	39.23**	84.72**	21.79**
W x E	6	0.083 <sup>ns</sup>	1.177**	0.900**	9.924**	0.091**	0.904 <sup>ns</sup>	6.811**	1.443**
Blocks	2	0.161	0.317	0.669	6.245	0.011	1.847	5.288	0.275
Residue	22	0.041	0.104	0.229	1.854	0.008	0.559	1.469	0.081
Total	35								
C.V (%)		16.22	9.62	12.82	20.13	15.40	8.94	25.14	11.40

\*, \*\*, ns - Significant for 5%, 1% and no significant, respectively, by Test F. DF – degrees of freedom.

**Table 4.** Mean values of chemical attributes of salinity and of sodium adsorption ratio (SAR) of the soil irrigated with different wastewater depths, before and after irrigation and after the rainy season.

Factors	EC	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	HCO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	SAR
Water Depths (mm) dS m <sup>-1</sup> ----- mmolc L <sup>-1</sup> -----								
692	1.36	3.32	4.14	8.04	0.80	9.18	6.03	2.78
554	1.32	3.15	3.51	7.24	0.51	7.21	4.95	2.77
416	1.08	3.48	3.57	4.66	0.58	8.60	3.65	1.74
278	1.23	3.20	3.71	7.10	0.52	8.46	4.65	2.72
LSD	0.26	0.42	0.62	1.78	0.12	0.97	1.58	0.37
Time dS m <sup>-1</sup> ----- mmolc L <sup>-1</sup> -----								
E1	1.58 <sup>a</sup>	3.25 <sup>b</sup>	4.31 <sup>a</sup>	10.92 <sup>a</sup>	0.22 <sup>c</sup>	6.41 <sup>c</sup>	7.87 <sup>a</sup>	3.97 <sup>a</sup>
E2	1.16 <sup>b</sup>	3.78 <sup>a</sup>	3.72 <sup>b</sup>	6.09 <sup>b</sup>	0.61 <sup>b</sup>	9.97 <sup>a</sup>	3.52 <sup>b</sup>	2.22 <sup>b</sup>
E3	1.00 <sup>b</sup>	3.06 <sup>b</sup>	3.17 <sup>c</sup>	3.26 <sup>c</sup>	0.97 <sup>a</sup>	8.71 <sup>b</sup>	3.06 <sup>b</sup>	1.32 <sup>c</sup>
LSD	0.20	0.33	0.49	1.39	0.09	0.76	1.24	0.29

E1 - before irrigation; E2 - after irrigation with 89 mm of rain during the crop cycle; E3 - after the rainy station with 646 mm. Means followed by the same letter in the column don't differ amongst themselves, by the test of Tukey for 5% of probability. DF – degrees of freedom. LSD – least significant difference.

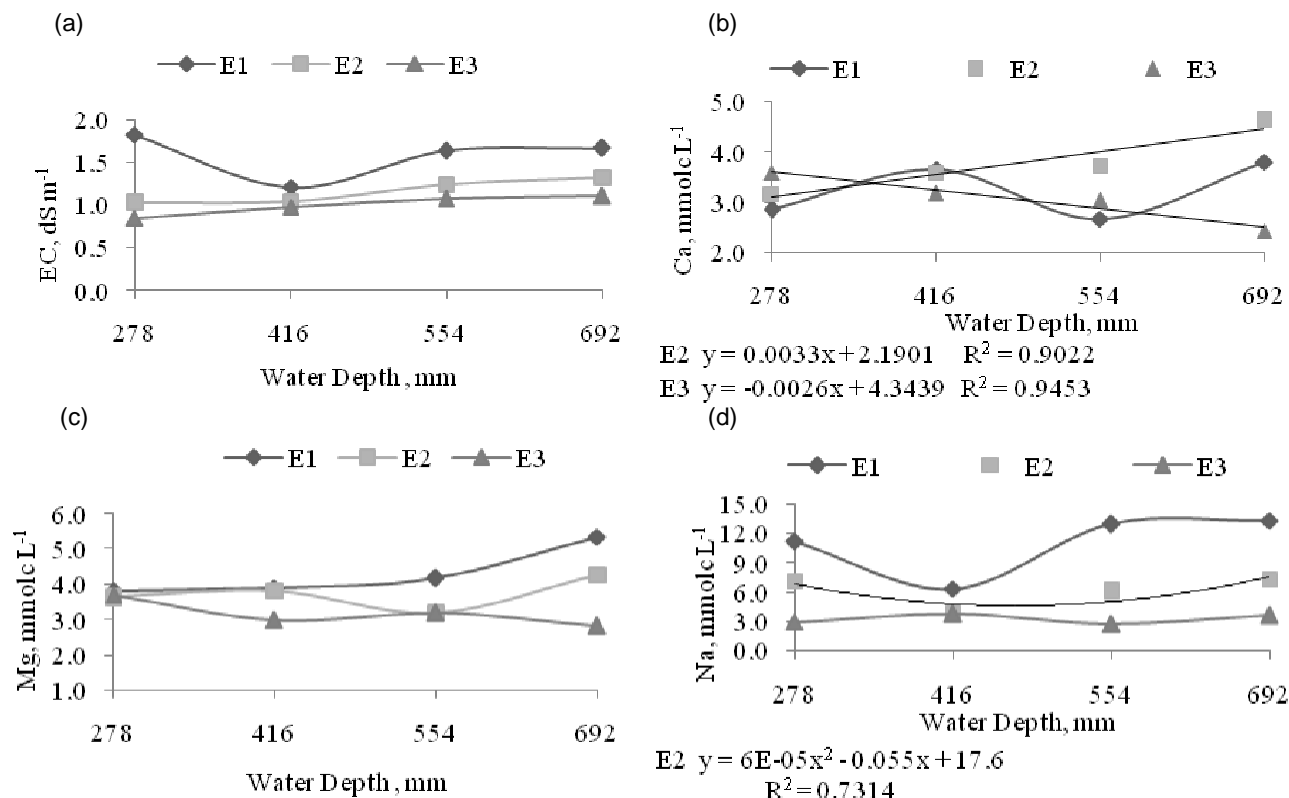
Argisols with 8, 16 and 32 mm of water, evaluating the levels of extractable K and P, organic carbon, pH (CaCl<sub>2</sub>), Ca<sup>2+</sup>, Mg<sup>2+</sup>, (H<sup>+</sup>, Al<sup>3+</sup>) and saturation by bases, found that due to the presence of nutrients in the water; the soil pH increased and the levels of Al<sup>3+</sup> decreased with the application of the treatments by virtue of the properties of soil acidity neutralization. Soil fertility increase occurred at the same levels as the mineral fertilization, when applying the dosages of 16 and 32 mm in wastewater. There were correction of acidity, insolubilisation of the levels of exchangeable aluminum in the soil and availability of the phosphorus element.

It is observed in Table 4 the mean values of chemical attributes of salinity and of SAR of the soil irrigated with different wastewater depths, before and after the irrigation and after the rainy season. In the factor time, the electrical conductivity of the saturation extract

decreased with time, certainly due to precipitations happened in the period. Also, the concentration of salts in the humid bulb formed by the emitter and the contents of magnesium, sodium, chloride and the sodium adsorption ratio decreased along the time, while the content of potassium increased. The pH before irrigation varied from 8.18 to 8.35; after irrigation and the rainfall of 89 mm the pH increased from 8.2 to 8.4 and after the rainy season of 646 mm the pH was among 8.1 and 8.3. The EC decreased with the precipitation of 89 mm and later with 646 mm.

According to Figure 3, the tendency of the contents of calcium after irrigation with wastewater and the rainfall of 89 mm was linear, increasing with increments of 0.0033 mmolc L<sup>-1</sup> mm<sup>-1</sup> (Figure 3b). With the rains of 646 mm happened the inverse, that is, the contents of calcium decreased in larger water depths. With magnesium





**Figure 3.** Electrical conductivity of the extract of saturation of the soil (EC), and contents of calcium, magnesium and sodium, before irrigation (E1), after irrigation (E2) and a rainfall of 89 mm, and after the rainy season of 646 mm (E3), in area irrigated with effluent.

something similar happened (Figure 3c); until the water depth of 554 mm there was not a tendency, from which up to the wastewater depth of 692 mm and with the precipitations of the five months, the contents of magnesium decreased.

The sodium decreased soon after the precipitation of 89 mm, decreasing much more with the precipitation of 646 mm (Figure 3d); in agreement with the regression analysis the smallest content of sodium of 4.95 mmolc L<sup>-1</sup> would happen in the wastewater depth of 461 mm. Thus, it is observed that there was a wash of the soil profile in the layer of 20 cm, where the soil samples were collected; possibly the great amounts of sulfates in the soil profile, originating from wastewater, might have contributed to a larger lixiviation of sodium. The potassium content after irrigation increased; in agreement with the regression analysis the smallest content of 0.37 mmolc L<sup>-1</sup> would be found in the wastewater depth of 439

mm (Figure 4a). There was an increase of the contents of potassium even with the precipitations happened in the five months; this increase certainly is linked to the application of the effluent rich in potassium.

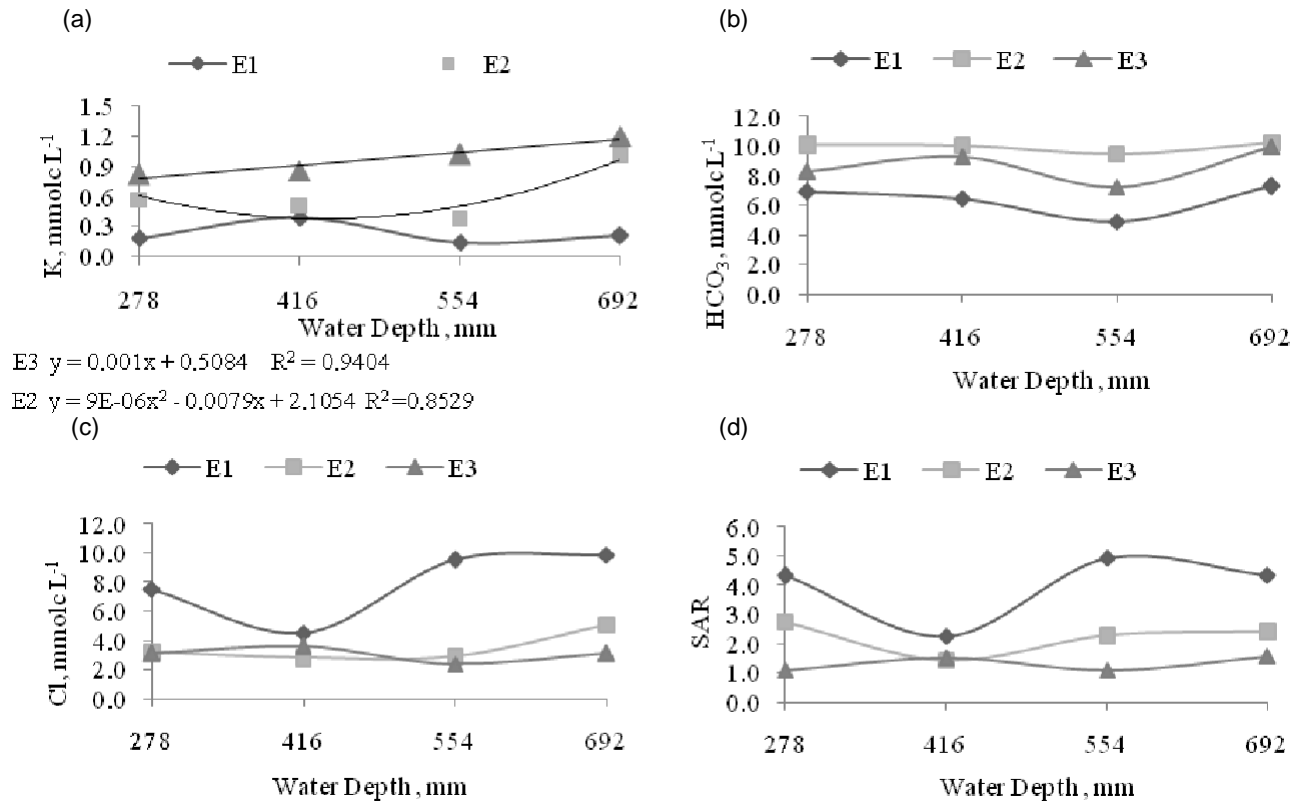
There was an increase of bicarbonate soon after the irrigation with effluent, decreasing afterwards with the pluvial precipitation of 646 mm (Figure 4b). The contents

of chloride decreased after the irrigation in the area, not existing a satisfactory tendency in relation to the amount of applied water (Figure 4c), decreasing with the precipitation in five months, with a larger reduction in the water depth of 692 mm, where the contents were higher. In general there was, however, a tendency of uniformity of the contents of the studied elements with the happened precipitations. The SAR decreased after irrigation and the precipitation of 89 mm, decreasing much more in five months of rainfall with precipitation in that period of 646 mm (Figure 4d).

Due to the fact that the effluent is usually saline, the irrigation with wastewater has been taking to increase of soil salinity (Cromer et al., 1984; Smith et al., 1996), which can affect the absorption of water by plants due to presence of a larger concentration of the ions Na<sup>+</sup>, Cl<sup>-</sup> and HCO<sub>3</sub><sup>-</sup> in soil solution (Bielorai et al., 1984).

However, some authors have been shown decrease in soil salinity with irrigation by effluent (Day et al., 1979; Stewart et al., 1990). In the first case, soil naturally saline was undertaken, and in the second one the authors verified that in a forest soil irrigated with treated sewer effluents for more than four years, the salinity was reduced due to lixiviation and to salts absorption by trees. Santos et al. (2006) studying the increasing salinity of





**Figure 4.** Contents of potassium, bicarbonate and chloride and the sodium adsorption ratio (SAR), before irrigation (E1), after irrigation (E2) and a rainfall of 89 mm, and after the rainy season of 646 mm (E3), in area irrigated with effluent.

the soil irrigated with wastewater and water supply and fertilized with biosolids and mineral manuring found that the wastewater increased the electrical conductivity of the soil by more than 130% in relation to the water supply; the doses of biosolids did not influence the concentrations of cations and anions. The highest values for the SAR and for the exchangeable sodium percentage (ESP) in the soil were observed in treatments with wastewater and biosolids doses of 75 kg ha<sup>-1</sup> of N. Irrigation with wastewater contributes to make the soil from not saline to saline-sodic.

## Conclusions

The contents of P, K<sup>+</sup>, Ca<sup>2+</sup>, H<sup>+</sup> and the capacity of cationic change of the soil increased after irrigation with wastewater, while the pH, the contents of Na<sup>+</sup> and Mg<sup>2+</sup> and the percentage of exchangeable sodium of the soil were decreased. There was a tendency of the contents of the studied elements, and the electrical conductivity and the sodium adsorption ratio of the extract of saturation of the soil to increase after irrigation with wastewater. The electrical conductivity of the extract of saturation of the soil, the contents of calcium, magnesium, sodium and chlorides, and the sodium adsorption ratio decreased

after five months of rainfall of 646 mm. A rainfall of 89 mm in six days was not enough to reduce the contents of calcium and bicarbonate of the extract of saturation of the soil.

## Conflict of Interest

The authors have not declared any conflict of interest.

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