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AGRICULTURAL ENGINEERING

Wastewater Reuse: impact on the chemical and macronutritional attributes of an inceptisol irrigated with treated domestic wastewater

INGENIERÍA AGRICOLA

Reúso de aguas residuales: impacto en los atributos químicos y macronutricionales en un suelo inceptisol irrigado con aguas residuales domésticas tratadas

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Resumen

Este estudio tuvo como objetivo estimar el potencial impacto en los atributos químicos y macronutricionales de un suelo inceptisol sembrado con caña de azúcar y sometido a tres diferentes tratamientos de riego: Efluente de la PTAR-C (T1), Agua de Pozo (T2) y Agua de Pozo más fertilización química (T3). Se instaló un experimento en bloques completos al alzar con parcelas divididas con tres repeticiones. Al final del estudio se encontró que las relaciones de bases químicas (Ca/Mg, Mg/K, Ca+Mg/K) mejoraron en todas las parcelas, en todos los tratamientos, situación que se ratifica al no encontrarse diferencias estadísticas significativas entre los tratamientos. Así mismo, se encontró que el tipo de tratamiento no influyó en la variación en los contenidos de los macronutrientes (N, P, K) del suelo. Los contenidos de materia orgánica, P, Na y K aumentaron; y disminuyeron los de nitrógeno inorgánico ($N-NH_4$, $N-NO_3$) independientemente del tratamiento, lo que permite inferir la no asociación de impactos adversos en el suelo por el reúso de agua residual tratada en riego de caña de azúcar.

Palabras Clave: Calidad de aguas, macronutrientes, propiedades químicas, riego agrícola.

Abstract

This study aimed to estimate the potential impact of wastewater reuse on the chemical and macronutritional attributes of an inceptisol cropped with sugarcane. The experimental design was in three randomized blocks, in split-plot design (three replicates per treatment), with three different irrigation treatments: treated wastewater (TWW) from Cañaveralejo wastewater treatment plant (WWTP-C); groundwater without any fertilizer (GW); and groundwater with chemical fertilizer (GW+CF). At the end of the study, plots with treated wastewater irrigation improved slightly Ca/Mg, Mg/K, and Ca+Mg/K ratios, increased OM, Na, P, and K contents and decreased pronouncedly inorganic nitrogen ($N-NH_4$; $N-NO_3$) of an inceptisol. Besides, we found that the type of treatment did not influence the variation of chemical attributes in soil, since statistically differences were no found in comparison among treatments. Therefore, our results suggest no adverse impact on chemical soil attributes due to wastewater reuse on sugarcane irrigation.

KeyWords: *Agricultural irrigation, chemical properties, macronutrients, water quality.*

1. Introduction

Agriculture is, so far, the largest consumer of global freshwater. Hence, it is the mainly responsible for the pressure upon this resource. Approximately 70% of total freshwater withdrawal is destined to agricultural irrigation. This is especially due to the growing demand for food products driven by population increase and changes in dietary patterns (UN-Water, 2009). If this tendency continues, in the near future, supply and development of primary socioeconomic activities will be compromised.

Agricultural irrigation with treated wastewater is regarded as a low-cost alternative and suitable strategy in water reclamation, since there are several positive results in this matter (Dreizin, 2007; Duan, et al., 2010; Santos, et al., 2012; Ribeiro, et al., 2012; Adrover, et al., 2012; Marinho, et al., 2013; Mora, et al., 2014). Hence, economic, environmental and social benefits would be obtained from TWW reuse on crops with both high-water demand and important socioeconomic impact, as sugarcane is. In addition, treated wastewater could enrich agricultural soils with elements like macronutrients (N, P, K) and organic matter (OM) (Xu, et al., 2010; Rezapour & Samadi, 2011).

However, some authors have pointed out that in spite of the unquestionable benefits, wastewater irrigation may have adverse impacts on both physiochemical and microbiological properties of the soil, which will influence soil fertility and productivity, raising important concerns about the sustainability of continued reuse of treated wastewater in agriculture (Becerra-Castro, et al., 2015). In fact, under tropical conditions, many questions remain unanswered respecting to positive or negative impacts upon soil properties as a consequence of disposal large volumes of TWW in agriculture (Pereira et al., 2011).

Within this context, this paper presents part of the results obtained of the research project tittle “Potential Reuse of Effluent from the Cañaveralejo Wastewater Treatment Plant (WWTP-C) in Sugarcane Irrigation in Valle del Cauca” (Echeverri, 2011; Pérez, 2012), which – particularly – estimated the potential impact on chemical attributes (exchangeable cations and their rations) and nutritional attributes (N, P, K) of a representative soil from the geographical valley of Cauca River cropped with Sugarcane (CC 85-92) and irrigated with effluent from the WWTP-C based in Cali-Colombia.

2. Materials and methods

2.1 Location

The study was carried out in area of 0.65-ha-plot, inside the WWTP-C facilities (3°28’17”N 76°28’52.8”W, 967 m.a.s.l.), located to the northeast of the city of Cali, on the left bank of the Cauca River. The WWTP-C performs primary treatment, especially operating under primary conventional treatment (PCT) or chemical enhance primary treatment (CEPT). Nowadays, it treats a monthly average flow rate of 6.55 $m^3 s^{-1}$, approximately 86% of the total wastewater generated in the city (Emcali, 2015).

2.2 Experimental design

The experiment was arranged in a completely randomized block design, in a split-plot scheme, with three replications. The irrigation treatments were: treated wastewater from WWTP-C (TWW), groundwater without any fertilizer (GW), and groundwater plus chemical fertilization (GW+CF). Three blocks installed were separated 12 m from each other. Each block, 100 m long and 1.5 m wide, was composed of nine furrows, three per treatment (Figure 1). Chemical (ions and exchangeable bases) and macronutritional (N, P, K) attributes of soil were monitored as response variables for each treatment (three furrows). The following expression represents the statistical model assumed (Ec.1):

$$Y_{ij} = \mu + A_i + B_j + E_{ij} \qquad (1)$$

Where, Yij: response variable, μ: population mean, Ai: effect of the i^th^ treatment, Bj: effect of the j^th^ block, Eij: experimental error associated to the i^th^ treatment in the i^th^ block.

Fertilization doses for GW+CF treatment were estimated according to soil analysis and following regional guidelines for sugarcane nutrition (Quintero, 1995) (Table 1). The nutritional requirements (N, P_2O_5, K_2O) were converted into their commercial equivalent (urea, triple superphosphate, and potassium chloride).

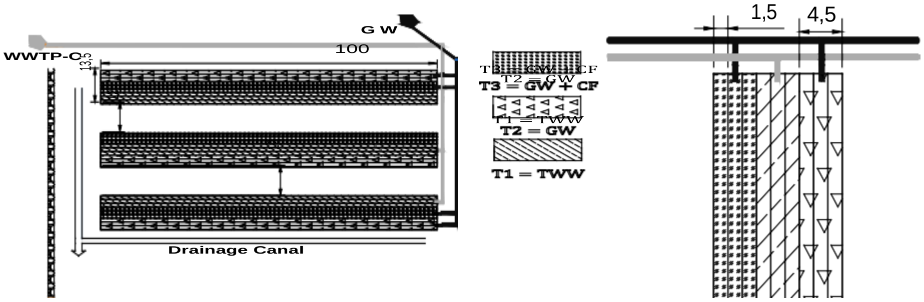

Figure 1. *General scheme of the experimental spot (not scale)*

Block	Nutritional Requirement (kg) N	P_2O_5	K_2O	Fertilizer (kg) Urea 46% N	Triple superphosphate 46% P_2O_5	Potassium chloride 60% K_2O
I	*4.5*	*0.0*	*0.0*	*9.8*	*0.0*	*0.0*
II	*4.5*	*2.0*	*3.4*	*9.8*	*4.4*	*5.7*
III	*4.5*	*0.0*	*0.0*	*9.8*	*0.0*	*0.0*
Total	**13.5**	**2.0**	*3.4*	*29.5*	*4.4*	*5.7*

Table 1 . *Fertilization doses applied for T3 (0.045 ha block^{-1})*

One-way ANOVA was performed when the independence, normality (Shapiro-Wilk test) and homogeneity of the variances (Levene test) were verified. Otherwise, nonparametric tests (Kruskal-Wallis) were performed in the analysis. Post hoc tests, Tukey-b for ANOVA and pairwise comparison for nonparametric test were used. IBM® SPSS® Statistics 20 software was employed for the analytical process.

2.3 Preparing soil and planting

Prior to seedlings manually planting (traditional way in Valle del Cauca), preparation of the plots were held (comprising plowing, raking, leveling, and furrowing). The sugarcane variety sown was CC 85-92, which was the most grown variety in the geographic valley of the Cauca River in 2010 (71.4% of the total area), with an average yield of 120 t ha^{-1} (Cenicaña, 2010).

2.4 Soil sampling and analysis

Prior to preparing soil, four 1-kg sample/ furrow were grabbed from upper soil layer in the first 40 cm, gathering a total of 12 subsamples per block, and then, were integrated per treatment to conform a 2-kg sample/treatment per block. In the laboratory, chemical (pH, Ca, Mg, Na, CEC, EC, ESP) and nutritional (N-NH_4, N-NO_3, OM, P-BrayII, K) attributes of soil were determined (Table 2). A similar procedure in soil sampling and laboratory analysis was repeated on the 12th month of the study period.

2.5 Initial soil attributes

The soil taxonomic category was a Vertic Endoaquepts, alluvial origin, and basic structure of 2:1 clay minerals (vertic features). As a consequence, clay fraction presented dominance in all their horizons. Such soil is representative in the geographical valley of the Cauca River, given that 28.6% of the soils fall in these characteristics (IGAC & CVC, 2004). In spite of medium Na content (0.1-0.5 cmol.kg^{-1}) and ESP (= 0.78%) less than 7% (onset of soil sodicity); there exists a potential danger in soil structure. High values in Mg content (>1.8 cmol.kg^{-1}) and its saturation

Block	pH	Ca	K	Mg	Na	CEC_7	Ca/Mg	Mg/K	Ca+Mg/K	EC	ESP	OM	P-BrayII	$N\text{-}NH_4$	$N\text{-}NO_3$
	Und			cmol kg^{-1}						**µmho cm^{-1}**	**%**	**gr kg^{-1}**		**mg kg^{-1}**	
I	7.41	23.52	0.33	9.5	0.25	29.55	2.5	29	100	274	0.74	35.93	29.46	14.96	13.19
II	7.42	21.21	0.26	8.93	0.25	26.6	2.4	34	116	215	0.82	25.09	6.62	11.21	9.02
III	7.41	23.88	0.31	8.93	0.26	30.2	2.7	29	106	222	0.78	33.74	18.74	8.52	16.17
Mean	7.41	22.87	0.30	9.12	0.25	28.78	2.5	31	107	237	0.78	31.59	18.27	11.56	12.79

***Table 2**. Chemical and macronutritional properties of soil and its cation ratios*

percentage (EMgP> 25%) can cause aggregate breakdown and soil dispersion as well as ionic imbalance. For instance, Ca/Mg (2.5:1), Mg/K (31:1) and Ca+Mg/K ratios were unbalanced from their ideal BCSR (basic cation saturation ratio) of 3-5:1, 6-8:1 and >40, respectively due to magnesium (Table 2).

According to the general standards for agricultural soil analysis by Castro & Gómez (2013), soil was classed as: calcareous soil (pH between 7.4-7.9) with low mineral contents in P (10-20 mg kg^{-1}), K (0.2-0.4 cmol kg^{-1}), $N\text{-}NO_3$ (<28 mg kg^{-1}); medium category in OM (3-5%), and high levels in Ca (>6 cmol kg^{-1}) and $N\text{-}NH_4$ (>9 mg kg^{-1}) as well as CEC (sum of bases) and CEC_7 (>20). Such soils, that having high Ca, Mg, and K contents, require high CEC –as in this instance - for holding these exchangeable cations coming from meteorization and fertilization, avoiding their loss through leaching (Galiano, 1995; Guerrero, 1995). Therefore, the initial soil presented favorable conditions for plants obtain mineral nutrients through root uptake from the soil solution. Besides, no type of agricultural activity had been developed on the soil.

2.6 Irrigation scheduling

A gated pipe system, furrow irrigation, was set (traditional method in Valle del Cauca) in the study area. Independent PVC pipes conveyed each irrigation resources, groundwater (GW) and treated wastewater (TWW), respectively. GW came from well VC-727, which withdraws water from a semi-confined aquifer, whereas, TWW came from the chamber that transports WWTP-C effluent to the final discharge (Cauca River). The irrigation water requirement was estimated by water balance (+effective rainfall +irrigation – crop evapotranspiration). Effective precipitation (Pe) was predicted by employing USDA-SCS on CROPWAT software, while ETc estimation by following CENICAÑA guidelines (Torres et. al. 2004). In that sense, five irrigation timings were scheduled throughout one phenological cycle: two net irrigation depths of 40 mm during the first four months (tillering), and the remaining amount (75 mm) between 4 and 10 months (fast growth). According to Torres *et al*. (2004) during the maturity period (10-13 months), is recommended to suppress irrigations to prevent plant growth and, thus, harvesting sugarcane with low saccharose contents in the stems.

2.7 Water quality for irrigation

Both GW and TWW physical-chemical parameters were determined in laboratory following standard procedures for examination of water and wastewater (APHA, 1999) (Table 3). A 2-liter sample of water was grabbed from the central gate of each treatment 10 minutes after starting each irrigation.

As can be noted in Table 3, most of the constituents in both water resources meet international (Ayers & Westcot, FAO 1985) and national (Res. 1207 of 2014) standards for irrigation water quality. As a matter of fact, both GW and TWW displayed similar characteristics: good physicochemical water quality for agricultural irrigation, on one hand with low sodicity hazard and moderate salinity hazard (C2S1) (USSL Staff, 1954) and on the other hand, with moderate sodicity hazard and low salinity hazard (C1S2) (Ayers & Westcot, FAO 1985). Likewise, except for NO_3, wastewater constituents meet maximum allowable limit in

Parameter	n	GW			TWW			Range for Irrigation
		Mean	Range	Stdev	Mean	Range	Stdev	
Electrical conductivity (EC_w dS m^{-1})	4	0.40	0.42-0.40	0.01	0.64	0.67-0.60	0.04	<0.7*
Acidity/Alkalinity (pH)	4	6.85	7.10-6.50	0.25	6.75	7.00-6.50	0.21	6.0-8.5*
Calcium (Ca^{++} mg L^{-1})	4	39.68	39.68-39.68	0.00	30.22	32.87-26.67	2.58	<400*
Magnesium (Mg^{++} mg L^{-1})	4	11.76	12.39-10.94	0.62	10.66	11.18-10.21	0.42	<60*
Sodium (Na mg L^{-1})	5	54.58	56.10-49.89	2.64	36.84	37.24-36.09	0.51	<200**
Bicarbonate (CO_3H^- mg L^{-1})	4	198.32	244.08-152.55	48.14	175.42	213.57-122.04	38.39	<840*
Chloride (Cl^{-1} mg L^{-1})	3	61.45	67.36-56.72	5.42	17.73	21.27-14.18	3.55	<300**
Sulphate (SO_4 mg L^{-1})	3	16.65	44.19-2.40	23.86	77.49	105.19-39.86	33.78	<500**
Nitrates (NO_3^--N mg L^{-1})	4	0.86	1.86-0.11	0.90	12.60	17.20-7.60	4.81	<5**
Ammonium nitrogen (NH_4-N mg L^{-1})	4	1.35	1.80-0.97	0.35	23.58	28.00-14.31	6.25	<5*
Phosphates (PO_4-P mg L^{-1})	5	0.10	0.10-0.10	0.00	1.40	3.29-0.36	1.22	<2*
Potassium (K^+ mg L^{-1})	5	6.73	7.04-6.26	0.33	8.05	8.21-7.82	0.21	<2*
$^+BOD_5$ (mg L^{-1})	12	--	--	--	104	133-76	14.8	--
^+COD (mg L^{-1})	12	--	--	--	268	310-214	23.5	--

Table 3. *Physical-chemical characteristics of the groundwater and treated wastewater*

**Ayers & Westcot (FAO 1985). n: data reported. $^+$Emcali (2011).*
***Maximum allowable limit in reclaimed wastewater in Col (Res. 1207, 2014).*

reclaimed wastewater in Colombia (Res. 1207, 2014).

3. Results and discussion

3.1 Final soil chemical attributes

The contents of Ca, Mg and Na in the soil are reported in Table 4. Both Ca and Mg in TWW presented slight decline, when compared with baseline values (Table 2). These cations did no show a statistical difference in comparison to other treatments ($p>0.05$) (Table 5). However, the wastewater irrigation increased Na contents in soils, and this treatment statically differed ($p<0.05$) from groundwater treatment. Barreto et al., (2013) found that the content of calcium and magnesium –in upper layer-, and sodium –in deeper layer- increased in the wastewater treatments at the end of a short period of study.

In their turn, Bedbabis et al., (2014), observed: a highly significant accumulation of Na in TWW irrigated soil, both Ca and Mg concentrations were similar in TWW and GW irrigated soils, and a significant decrease of Mg contents after 4 years of irrigation with treated wastewater. It is important to point out that Na levels are below the critical limits found in the literature (Castro & Gomez, 2013), however, domestic effluents are rich in sodium which can accumulate on the soil and cause soil sealing (Marinho, et al., 2013).

Treated wastewater also enhanced slightly the Ca/Mg, Mg/K and Ca+Mg/K ratios (Table 4), attaining the ideal ranges (3-5:1, 6-8:1 and >40), mainly due to exchangeable K^+ in wastewater, which could be the solution for improving soil's CEC without using fertilizers. Nevertheless, this situation occurred in GW and GW+CF treatments in the same way, undermining the treatment influence.

3.2 Final soil macronutritional attributes

In general terms, organic matter (OM) concentrations enhanced considerably regardless the treatment in all blocks ($p>0.05$) at the end of the study (Table 6). The OM content in fertilizer treatment was higher than TWW and GW. A natural process in sugarcane could slightly alter these results somehow. Since plant material expelled by the crop, and decomposed gradually, that remain in the soil as crop residues (Quintero, 1995), may be incorporated into the grabbed soil sample.

In contrast, Sousa, et al., (2006), after ending their experience, noted that vermicompost treatments and effluent (UASB reactor) contrasted significantly high values of OM above the other treatments, which included mineral fertilization and well water. The increment of its concentration in the soil as a result of treated wastewater irrigation has been also reported for several authors (Xu, et al., 2010; Adrover, et al., 2012; Barreto, et al., 2013; Bedbabis, et al., 2014). Moreover, OM rose as well as pH did in all treatments. This result contrasts to the hypothesis of if OM value increases, the H^+ ions increase in the soil matrix and, hence, it tends to acidify (pH diminishes). In this way, Sou, et al., (2013), reported that the OM contained in the wastewater was largely dissolved due to a sharp soil pH increase (higher than 8.0), 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.

In the meanwhile, inorganic nitrogen (NH_4, NO_3) contents diminished significantly compared to the initial soil state in all blocks and treatments (Table 6). Thus significant differences were not found ($p<0.05$) among TWW, GW and GW+CF (Table 7). This result may be attributing to two factors. The great nitrogen uptake, especially in the NO_3 and NH_4 forms, by sugarcane roots (Quintero, 1995), and its high mobility in soil (Castro & Gomez, 2013). Furthermore, the increment in soil N concentration can be provided by the own WWTP-C, since It has been found that the application of its biosolids rises the content of organic nitrogen in soil, increasing mineralization in such soil (Silva, et al., 2013).

Block	Treatment	Ca	Mg	Na	CEC_7	pH	Ca/Mg	Mg/K	Ca+Mg/K	EC	ESP
			cmol kg^{-1}			Und		%		µmho cm^{-1}	%
I	TWW	18.63	7.39	0.45	31.1	7.54	2.5	12.3	43.4	218	1.67
	GW	17.43	6.18	0.42	34.0	7.49	2.8	9.0	34.2	0	1.69
	GW+CF	22.12	6.34	0.35	29.9	7.57	3.5	9.3	41.9	243	1.20
II	TWW	23.09	8.26	0.26	34.7	7.58	2.8	11.6	44.2	220	0.80
	GW	21.47	9.17	0.32	33.9	7.65	2.3	17.0	56.7	0	1.00
	GW+CF	24.39	9.16	0.24	36.4	7.41	2.7	12.1	44.1	223	0.69
III	TWW	23.55	8.56	0.32	36.1	7.61	2.8	26.8	100.3	199	0.98
	GW	22.23	10.12	0.40	36.9	7.51	2.2	15.8	50.5	0	1.18
	GW+CF	19.99	7.19	0.27	33.2	7.58	2.8	13.6	51.3	238	0.98
Mean	TWW	21.76	8.07	0.34	33.97	7.58	2.7	16.9	62.6	213	1.12
	GW	20.38	8.49	0.38	34.93	7.55	2.5	13.9	47.2	0	1.26
	GW+CF	22.17	7.56	0.29	33.17	7.52	3.0	11.6	45.8	235	0.94

Table 4. *Chemical properties of soil and its cation ratios*

Parameter	Treatments compared	F-value*	ρ	d.f.
ESP	TWW, GW, GW+CF	3.44	0.092	3
EMgP		1.94	0.224	3
Ca		0.65	0.613	3
Mg		0.98	0.464	3
Na		5.29	0.040	2

Table 5*. ANOVA summary of chemical attributes*
**significance level of 0.050*

Block	**Treatment**	**OM** g kg^{-1}	**P-BrayII** mg kg^{-1}	**K** cmol kg^{-1}	**N-NH$_4$** mg kg^{-1}	**N-NO$_3$** mg kg^{-1}
I	*TWW*	*42.18*	*61.84*	*0.60*	*1.00*	*5.38*
	GW	*43.32*	*47.95*	*0.69*	*2.03*	*0.00*
	GW+CF	*43.68*	*52.01*	*0.68*	*0.85*	*0.00*
II	*TWW*	*42.99*	*57.48*	*0.71*	*0.41*	*0.07*
	GW	*37.03*	*32.04*	*0.54*	*0.69*	*0.04*
	GW+CF	*50.03*	*65.22*	*0.76*	*1.23*	*1.65*
III	*TWW*	*38.31*	*44.28*	*0.32*	*0.65*	*6.13*
	GW	*39.54*	*61.09*	*0.64*	*0.37*	*4.02*
	GW+CF	*46.14*	*66.31*	*0.53*	*0.47*	*0.04*
Mean	*TWW*	*41.16*	*54.53*	*0.54*	*0.69*	*3.86*
	GW	*39.96*	*47.03*	*0.62*	*1.03*	*1.35*
	GW+CF	*46.62*	*61.18*	*0.66*	*0.85*	*0.56*

Table 6. *Macronutrient concentration of soil*

Parameter	*Treatment compared*	*F-value**	*ρ*	*d.f.*
OM (g kg^{-1})	*TWW, GW, GW+CF*	*4.27*	*0.070*	*2*
N-NH$_4$ (mg kg^{-1})		*0.26*	*0.777*	*2*
N-NO$_3$ (mg kg^{-1})		*-*	*0.188***	*-*
P-Brayll (mg kg^{-1})		*1.26*	*0.350*	*2*
K (cmol kg^{-1})		*0.51*	*0.625*	*2*

Table 7. *ANOVA summary of macronutritional attributes*

**significance level of 0.050. ** Non-parametric test (Kruskal-Wallis test)*

Both P and K cation concentrations, whose values increased (almost double) among all the treatments at the end of the study (Table 6), did not statistically differ in the treatments (p>0.050, Table 7). The higher P and K contents (treatment means) were observed in fertilizer treatment. Regarding phosphorus, the reason can be easily explained by looking Block II over. The initial P value in Block II was lower than Block I and III, thus, application of triple superphosphate took place, which rose P content over TWW and GW at the end of the study. GW treatment, which did not receive nutrients beyond natural conditions, presented the lower value both in Block II and treatment average. Also it is important to point out that the accumulation observed is basically due to the low mobility of P (as well as K) in the soil and its retention by clay minerals. The increased P content in soils irrigated with effluent from wastewaters has been reported by several researchers, who stated that such upswing is more notorious, especially on soil upper layers (Medeiros, et al., 2005a, 2005b; Rezapour & Samadi, 2011; Barreto, et al., 2013).

Concerning potassium (Table 6), TWW treatment showed the lowest average (as well as in Blocks I and III) concentration among treatments (0.54), although had a notable contribution from the treated wastewater in all blocks. Medeiros, et al., (2005a, 2005b) stated that K concentration in effluent treatments and conventional fertilization had a considerable increase of the content in the first soil layer (0-20 cm) at the end of study, and conventional fertilization influenced by the application of potassium chlorate had a significantly higher increase with respect to the effluent. Likewise, Heidarpour, et al., (2007) reported that the amount of K in the upper soil layers irrigated with wastewater was significantly greater than those irrigated with groundwater. However, the results found in the literature are divergent, since in some cases it has been observed that the treated wastewater reclamation caused decline of K^+ contents, and others that the application of TWW caused decrease of K^+ exchangeable soil (Medeiros, et al., 2005b).

Finally, the concentrations of chemical constituents in soil layers are influenced by water movement patterns, chemical concentrations in irrigation water and plant uptake (Heidarpour, et al., 2007). Thus, and given the dispersion seen in some plots at the end of the study (Table 4 and 6), a nutrient leaching may have occurred. Low efficiency from irrigation system (furrow method) propitiated runoff and the nutrients horizontally spread on soil due to the predominance of the clay content in the soil and furrow slopes. In this sense, localized irrigation would be more appropriated for wastewater reclamation in agriculture.

4. Conclusions

Both groundwater and effluent from the WWTP-C are classed as a good physiochemical water quality for irrigation, with a moderate salinity hazard (C2S1) (USSL Staff, 1954) and moderate sodicity hazard (C1S2) (Ayers & Westcot, FAO 1985). Likewise, except for NO_3, wastewater constituents meet maximum allowable limit in reclaimed wastewater in Colombia (Res. 1207, 2014).

After 12 months of irrigating sugarcane with treated wastewater the inceptisol properties changed as follow: Ca/Mg, Mg/K, and Ca+Mg/K ratios improved slightly; OM, Na, P, and K increased; and inorganic nitrogen (N-NH_4; N-NO_3) decreased pronouncedly. Besides, we found that the type of treatment did not influence the variation of chemical attributes in soil, since statistically differences were no found in comparison among treatments, which might be due to either leaching nutrients caused furrow irrigation systems or few time of research. In that sense, our results suggest no adverse impact on chemical soil attributes due to wastewater reuse in sugarcane irrigation.

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