Performance of a facultative pond in attendance to physicochemical water quality guidelines and nutritional load requirements for agriculture irrigation reuse

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Abstract With the purpose to investigate the effects on soil, groundwater and plant system, the effluent of a facultative stabilization pond was reused as water and nutritional resource for maize cultivation (Zea mays L.). This paper describes the unit performance with respect to the attendance to agricultural water quality guidelines and to nutritional requirements of the plant during two different cycles of culture.

The effluent was not classified as water that presents high potential to soil salinization, but it presented a little to moderate grade of sodicity. Even though it didn't present potential toxic due Boron, concentration values of Na and Cl were an indication to moderate use restriction. The research indicated that must not be considered any toxic effects to the plant because of the excessive presence of toxic compounds. Although the high average value of 36 mgTSS/L, clogging and other related problems were not observed on the irrigation system devices.

As the irrigation protocol attended the plant hydric demand, the effluent reuse procedure was able to apply N load in excess and P and K load in deficit, according to plant nutritional requirements. Consequently, local meteorological conditions didn't allow the experiment characterization as a classical fertirrigation.

Keywords Waste stabilization pond; facultative pond, toxic chemicals, agricultural reuse

INTRODUCTION

Due to water scarcity and quality constraints, expanding demands for water are certain to increase the competition and conflicts among uses. In the developing world, agriculture is an important component of national economies and in general represents two-thirds or more of the total water consumption. Water reuse by agriculture irrigation of treated sewage must contribute for the minimization of water related problems and nutrients presence may represent an economical beneficit for the agriculture sector.

Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts that it contains and that remain in the soil as water evaporates or is used by the crop. Water quality is judged on the potential severity of problems that can be expected to develop during long-term use which affect the accumulation of the water constituents and which may restrict crop yield. The soil problems most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity and a group of other miscellaneous problems (Ayers and Westcot, 1994).

The salinity is measured in terms of the Electrical Conductivity of the water and represents its ability to conduct an electric current in function of the dissolved substance presence. The excessive accumulation of dissolved solids in the radicular zone of the plant compromises the plant mechanisms of water absorption. The osmotic adaptation capacity of the plant corresponds to its tolerance level to the salinity of the soil soluble extract (Embrapa, 1993). Table 1 establishes the irrigation water quality guidelines based in the salinity content (Ayers and Westcot, 1994).

Tabel 1: Irrigation water quality guidelines based in the salinity content

Parâmetro	Use restriction		
	None	Little to Moderate	Strict
EC (dS/m)	< 0.7	0.7 – 3.0	> 3.0
TDS (mg/L)	< 450	450 – 2000	> 2000

While Na provokes the clay mineral dispersion, being able to cause the blockage of soil empty spaces, Ca contributes for the stability of its aggregates and physics structure. Additionally, the exchangeable Mg excess in the ground can induce to the Ca deficiency. The relation between the three cations is expressed by the Sodium Adsorption Ratio (SAR), in accordance with the expression: $RAS = Na^{+}/((Ca^{2+} + Mg^{2+})/2)^{0.5}$, expressed in $(mmol/L)^{0,5}$.

Both, salinity and sodicity act on the mechanisms of water infiltration in the soil, and the continuous irrigation of waters containing high ratios between Na and Ca, as the same of high RAS, compromises the physical structure of the soil superficial layers (Embrapa, 1993). Table 2 simultaneously establishes the irrigation water quality guidelines based in the sodicity content, considering the Electrical Conductivity and the SAR (Ayers and Westcot, 1991).

Table 2: Irrigation water quality guidelines based in the sodicity content

SAR	Use restriction		
	None	Little to Moderate	Strict
	EC (dS/m)		
0 - 3	> 0.7	0.7 – 0.2	< 0.2
3 - 6	> 1.2	1.2 – 0.3	< 0.3
6 - 12	> 1.9	1.9 – 0.5	< 0.5
12 - 20	> 2.9	2.9 – 1.3	< 1.3
20 - 40	< 5.0	5.0 – 2.9	< 2.9

The excessive absorption of ions by the plant can elapse in severe toxic effects, mainly caused by the accumulation in leaves in function of perspiration. Although some oligoelement can be toxic even under low concentrations, Cl, Na and B are distinguished as those capable ones to cause necrosis and burnings in the vegetal tissue (Embrapa, 1993). Table 3 establishes the irrigation water quality guidelines based in the toxic content, and according to short term effects (Ayers and Westcot, 1991).

Problems of blockage in irrigation system devices must occur in function of excessive suspended solids presence. Ayers and Westcot (1991) suggest that concentration values under 50 mgTSS/L cannot cause clogging problems and values higher than 100 mgTSS/L are inappropriate for irrigation devices.

Carbon, hydrogen and oxygen are nutrients captured by the plant from the air and water, as well are macro and micro-nutrients present in soil solution. The presence of N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, Mo, Ni and Zn in the soil is highly heterogeneous and depending on quantities that they appear, those elements may be beneficial to plant nutrition, but can also confer toxicity to agricultural culture.

Anyway, the plant nutrition requires the application of appropriate quantities of macro-nutrients along time (Embrapa, 1993). In general, the soil does not exactly respond to the exercised nutritional demand of the plant, and there is a need for agricultural crop management, which includes the use of mineral fertilizers or organominerals.

Table 3: Irrigation water quality guidelines based in the toxic content

Parameter (mg/L)	Use restriction		
	None	Little to Moderate	Strict
Na	< 70	> 70	-
Cl^-	< 100	> 100	-
B	< 0.7	0.7 – 3.0	> 3.0
		Short term effects	
Al		20.0	
As		2.8	
Cd		0.05	
Co		5.0	
Cr		10.0	
Cu		5.0	
F		15.0	
Fe		20.0	
Mn		10.0	
Mo		0.05	
Se		0.02	
Zn		10.0	

METHODS

The project was developed in the Wastewater Treatment Research Center of the Rio de Janeiro Federal University (WTRC-UFRJ), whose geographic coordinates are: 22°51'31" of south latitude and 43°14'3” of longitude west. The laboratory receives part of the university campus sewage and comprises 13 different unit processes and technologies, and among them a facultative stabilization pond with the following dimensions for average depth: 12.63 m length, 2.78 m width, and 1.62 m depth. The unit internal slopes are 1:2.5, resulting in a superficial area of 46.05m². With the purpose to investigate the effects on soil, groundwater and plant system, the facultative pond effluent was used as irrigation water and nutritional resource for the cultivation of two cycles of maize (Zea mays L.), according to the weekly hydric demand of the plant.

During the research, the facultative stabilization pond was operated under two different conditions: average superficial organic loads of 250 and 350 kgDBO/ha.d, corresponding to 7 and 9 days hydraulic detention time. Such loads are typical for the tropical climate conditions of Brazil (Jordão and Pessoa, 2005). Under the operational condition of 250 kgDBO/ha.day and 9 days detention time, tracer assays were run twice for the characterization of the hydrodynamic behavior and kinetics of the facultative pond. The same high dispersion number and equals to 0.54 was obtained on both assays and indicated significant internal recirculation of the liquid mass. According to the non ideal dispersed flow model, the average $K_{20°}$ value equals to 0.21 d^{-1} was also calculated (Volschan Jr. and Jordão, 2006). Figure 1 shows the WTRC-UFRJ facultative stabilization pond and the maize cultivation experiment.

All the physical and chemical parameters were analysed by the WTRC-UFRJ and the Brazilian Agricultural Research Corporation (Embrapa), according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1998). The facultative pond performance in attendance to water quality guidelines and nutritional load requirements for agriculture irrigation reuse was evaluated according to Ayers and Westcot (1991) and to Embrapa technical recommendations (EMBRAPA, 1993).

Figure 1: Facultative stabilization pond and the maize cultivation experiment

RESULTS AND DISCUSSION

The facultative pond effluent characteristics obtained during two cycles of maize cultivation and related to salinity, sodicity, toxic content and clogging are presented in Table 4. It also indicated the facultative pond performance in terms of the removal efficiency of each compound.

Table 4: Facultative pond effluent quality and removal efficiency

Statistics		unit	Effluent concentration					Average removal efficiency (%)
			Data	Average	Minimum	Maximum	Standard Deviation	
Salinity	EC	ms/cm	30	0.55	0.38	0.77	0.1	-
	TDS	mg/L	28	320	109	538	85	-
Sodicity	Ca	mg/L	30	32	18	46	9	<10
	Mg		29	10	6	19	3	<10
	SAR	mmol/L	34	3	1	5	1	-
Toxic content	Na	mg/L	30	106	53	171	31	<10
	Cl		24	112	70	232	36	<10
	B		27	0.09	0.03	0.36	0.07	42
	Al		31	0.25	≅ 0	0.79	0.21	81
	As		30	≅ 0	≅ 0	≅ 0	≅ 0	-
	Cd		31	≅ 0	≅ 0	≅ 0	≅ 0	-
	Co		30	≅ 0	≅ 0	≅ 0	≅ 0	-
	Cr		30	0.01	≅ 0	0.07	0.01	76
	Cu		30	0.03	0.01	0.09	0.02	56
	F		24	0.57	0.45	0.77	0.08	<10
	Fe		31	1.26	0.37	2.76	0.55	79
	Mn		30	0.16	0.08	0.4	0.06	30
	Mo		30	≅ 0	≅ 0	≅ 0	≅ 0	-
	Se		31	≅ 0	≅ 0	≅ 0	≅ 0	-
	Zn		30	0.07	0.01	0.15	0.04	74
	Ni		30	0	0	0.01	0.01	69

Irrigation	TSS	mg/L	32	36	9	89	21	80

Electrical Conductivity and Total Dissolved Solids values did not restrict the irrigation use of the facultative pond effluent in terms of salinity. The combination between SAR and Electrical Conductivity values shows that only a little restriction due to sodicity may be associated to the pond effluent quality, certainly because Na concentrations were most of the time above the guideline level. The average values of Na and Cl give also a little restriction to the effluent pond use with respect to toxic content.

In the other hand, should be discarded any toxic effects due to the excessive presence of others toxic trace elements in the pond effluent. It may be justified because they were naturally presented on the raw sewage at low concentrations, but also because most of them appeared as suspended particles and suitable to be settled on the facultative pond, as shown the removal efficiency average values on Table 3. The following low values of filtered and total cations average ratios also appear as a positive factor for trace elements removal by sedimentation: Mn, 0.31; Fe, 0.45; Zn, 0.06; Cu, 0.17; Cr, 0.03; Ni, 0.37; Al, 0.14; Cd, 0.02; Co, 0.02; and Sb, 0.23.

Even the presence of algae in the pond effluent contributed to the average TSS concentration of 36mg/L, problems of clogging and blockage were not observed in the low pressure sprinkling irrigation system during the two cycles of cultive.

According to the plant hydric demand and considering that it must be respected along the entire cultivation period, specifically between the 30th and the 60th days, the 60th and 90th days, and at the end of the cycle, the treated sewage irrigation practice was not able to correctly input the required macro-nutritional load of the mayze culture, as shown on Table 4.

Table 4: Nutritional load applied trough wastewater reuse

Nutrient	Cycle	Nutritional application										
		recomendation		experiment		recomendation		experiment		end of the cycle		
		30-60 days		43 days		60-90 days		92 days		recomendation	Experiment	
		%	kg/ha	kg/ha	%	%	kg/ha	kg/ha	%	kg/ha	kg/ha	%
N	1st	41	41	14.53	35	88	88	24.79	28	100	37.70	38
	2nd		41	40.20	98		88	137.75	131		143.15	143
P	1st	27.5	22	6.65	30	74	59.2	9.72	16	80	12.56	16
	2nd		22	5.79	26		59.2	15.66	26		23.71	30
K	1st	72.4	72.4	24.44	34	100	100	40.14	40	100	57.97	58
	2nd		72.4	21.15	29		100	67.28	67		104.35	104

During the 1st cycle of maize cultivation, because high rainfall intensity and frequency, limited irrigation volumes were applied according to the hydric demand of the plant. Consequently, N, P and K load requirements were not satisfied along the entire cycle, resulting at the end, the application of only 38% of the desired N, 16% of P and 58% of K.

During the 2nd cycle, the rainfall regime allowed the irrrigation of higher volumes of treated sewage and according to the facultative pond effluent characteristics, higher nutritional load was applied. Even N load requirements were almost satisfied during the entire cycle, it must be observed that K load was achivied only at the end of the cycle, and P requirements were not achivied at any time.

These results suggest that according to the local climate conditions, the facultative pond effluent agricultural reuse couldn't be characterized as a classical fertirrigation, but just an irrigation procedure of treated wastewater containing some level of macro and micro nutrients, and that should be agronomically optmized with the balanced addition of chemical P and K.

CONCLUSIONS

The facultative pond effluent characteristics did not restrict the irrigation use in terms of salinity. The combination between SAR and Electrical Conductivity gave only a little use restriction due to sodicity. With respect to toxicity, should be discarded any effects due to the excessive presence of toxic trace elements. Problems of clogging and blockage were also not observed in the low pressure sprinkling irrigation system.

Limited irrigation volumes were applied according to the hydric demand of the plant and consequently, N, P and K load requirements were not satisfied along the entire 1st. cycle of maize cultivation. During the 2nd cycle, K load was only partially achivied and P requirements were not achivied at any time. On this experiment, considering the local climate conditions, the agricultural wastewater reuse couldn't be characterized as a classical fertirrigation.

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