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THE INFLUENCE OF CHLORINATED WASTEWATER ON THE YIELD AND THE NITRIFICATION PROCESS IN IRRIGATED AREAS

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ABSTRACT

The aim of this experiment was to evaluate the relevance of chlorinated wastewater use in irrigation. Bearing this purpose in mind an experiment in pots with *Lolium multiflorum* Lam. was made. The soil used (cambisoil) was acid and poor in organic matter.

Chlorination with NaClO was made with three levels of free residual chlorine: 1; 3 and 5mg.L^{-1}. It was observed that chlorination did not influence the yield, and it decreased the nitrates level in the soil. It was also observed that the wastewater chlorination reduced the nitrification. A particular relevance should be given to the latter. On the one hand, it is certain that the decrease of nitrification may be harmful for soil fertility; on the other hand groundwater pollution risks will decrease.

INTRODUCTION

Water resources are not very abundant in Portugal. So they should firstly be used to satisfy municipal demands and other uses requiring high quality water.

Since the Mediterranean climate (by Köppen) has dry and hot summers, crops must be irrigated due to lack of water in the soil; therefore, in Portugal irrigation is necessary in order to increase agricultural productivity.

Thus, agriculture uses large quantities of water. The agricultural water needs is about 61% of the total sectorial needs and agriculture is by far the largest water consumer accounting for 89% of the total consumptions. Although it does not mean the use of high quality water, irrigation with treated urban wastewater may be an alternative to be taken into account in our country.

The correct use of irrigation with treated urban wastewater leads to water preservation and nutrients recycling. It avoids surface and groundwater pollution and it can also be used as a restoring method for groundwater (WHO,1989; Asano *et al*, 1992).

In order to irrigate a particular area, wastewater should undergo a treatment according to the characteristics of wastewater itself, climate, soil composition and crop.

Since the biological characteristics of wastewater may have an adverse impact on public health, an experiment with disinfected wastewater (with sodium hipoclorite) was carried out in the Instituto Superior de Agronomia-Lisbon, and it was planned with the goal of evaluating the effect of chlorination in some soil characteristics and plant yield as well as the relevance of wastewater use in irrigation.

MATERIALS AND METHODS

An experiment in pots using *Lolium multiflorum* Lam. was carried out. The soil used was a cambisoil. Table 1 shows the main characteristics of this soil, where its acidity, low organic matter content, low level of "available " phosphorus and medium level in "available" potassium, low cation exchange capacity and low degree of bases saturation are evident.

Table 1 - Soil characteristics

Parameters	
Texture	Loamy sand
E.C. ($mS \cdot cm^{-1}$)	0,058
O.M. (%)	1,29
N-Nk ($mg \cdot kg^{-1}$)	340
$N-NO_3$ ($mg \cdot kg^{-1}$)	vest.
PH (H_2O)	4,9
"Available" Phosphorus (P_2O_5, $mg \cdot kg^{-1}$)	16
Available" Potassium (K_2O, $mg \cdot kg^{-1}$)	100
Exchangeable H^+(cmol (+)$\cdot kg^{-1}$)	7,43
Exchangeable bases (cmol (+)$\cdot kg^{-1}$)	
Ca	1,07
Mg	0,20
K	0,11
Na	
T (cmol (+)$\cdot kg^{-1}$)	9,09
V (%)	18

The methods used in the analysis of the soil were : the organic matter was calculated by multiplying the percentage of organic carbon by the factor 1.724. Organic carbon was measured by dry combustion at 1200°C in a Ströhleinn apparatus. "Available" phosphorus and potassium in the soil were determined by colorimetric and flame emission photometric methods, respectively, after extraction by the Egner-Riehm method. Electrical conductivity was determined by a conductimeter apparatus in a 1:5 suspension (soil:water). Kjeldahl nitrogen ($N-N_k$) by Kjeldahl method and nitrates by a $N-NO_3$ ion-selective electrode. The exchangeable bases were determined by atomic absorption spectrophotometry after extraction by Mehlich method.

The irrigation water used was either the secondary effluent of the wastewater treatment plant in Beirolas-Lisbon, or deionized water according to the experiment. The wastewater used was treated by an activated sludge process. Both wastewater and deionized water were disinfected in the laboratory with sodium hypochlorite (WPCF,1986) in order to obtain, according to the experiment, three levels of free residual chlorine: 1; 3 and $5 mg.L^{-1}$. The disinfection was made by using a sodium hypoclorite solution having 7% of active chlorine.

Table 2 - Wastewater analytical results

parameters	**18-5-92**	**22-5-92**	**16-6-92**	**25-6-92**	**7-7-92**
TS ($g \cdot L^{-1}$)	0,69	0.63	0.56	0.60	0.76
TVS ($g \cdot L^{-1}$)	0,29	0.23	0.12	0.27	0.16
TSS ($g \cdot L^{-1}$)	0,05	0.04	0.07	0.06	0.05
COD($mg \cdot L^{-1}$)	66.68	55.13	55.09	54.50	102.38
BOD_5 ($mg \cdot L^{-1}$)	9.00	vest.	vest.	vest.	20.00
EC_W ($mS \cdot cm^{-1}$)	1.09	0.99	0.92	0.50	1.37
pH	7.8	7.9	7.7	8.3	7.7
NK (N, $mg \cdot L^{-1}$)	42.90	22.40	43.80	34.00	43.00
NH_4^+ (N, $mg \cdot L^{-1}$)	39.00	20.00	36.13	18.00	34.32
NO_3^- (N, $mg \cdot L^{-1}$)	39.20	15.40	53.20	30.80	70.00
Cl^- ($mg \cdot L^{-1}$)	118.04	118.93	127.80	134.60	200.50
P (P_2O_5 ($mg \cdot L^{-1}$)	3.69	5.10	3.00	9.63	10.73
K ($mg \cdot L^{-1}$)	32.50	42.50	16.75	11.13	15.63
Ca ($mg \cdot L^{-1}$)	62.50	63.00	45.75	43.91	50.75
Na ($mg \cdot L^{-1}$)	82.50	78.44	88.00	141.25	119.75
Mg ($mg \cdot L^{-1}$)	7.50	6.88	5.50	6.50	5.75
B ($mg \cdot L^{-1}$)	1.58	1.84	1.35	1.20	1.67

Several samples of wastewater were taken and analysed during the experiment. Table 2 shows the analytical results, and table 3 shows the amount of NaClO used in the disinfection.The methods used in the analysis of wastewater were those described in Standard Methods (1980) and AOAC Methods (1980).

Table 3 - Amount of sodium hypochlorite (NaClO) added to wastewater or deionized water ($\mu l \cdot L^{-1}$)

	18-5-92	22-5-92	16-6-92	25-6-92	7-7-92	
WWCl1		57.64	80.00	67.30	71.40	86.40
WWCl3		92.98	115.28	102.58	106.68	121.68
WWCl5		128.20	150.56	137.86	141.96	156.96

DWCl1	DWCl2	DWCl3	DWCl5
17.64	35.28	52.92	88.20

After air drying, the original soil was sieved in a 5mm sieve and it was divided into 12.0 Kg portions into twenty-four pots.
The addition of lime and nutrients was manual. All the pots were irrigated until field capacity with deionized water, before sowing.
During the experiment the soil moisture was mantained at 80% of the field capacity and chlorinated wastewater or deionized water irrigation was applied.

The following treatments were used in the present experiment:

chlorinated wastewater with a free residual chlorine $\leq$ 1mg.L^{-1} ($WWCl_1$)

chlorinated wastewater with a free residual chlorine $\leq$ 3mg.L^{-1} ($WWCl_3$)

chlorinated wastewater with a free residual chlorine $\leq$ 5mg.L^{-1} ($WWCl_5$)

deionized water ($DWCl_0$)

chlorinated deionized water with a free residual chlorine $\leq$ 1mg.L^{-1} ($DWCl_1$)

chlorinated deionized water with a free residual chlorine $\leq$ 2mg.L^{-1} ($DWCl_2$)

chlorinated deionized water with a free residual chlorine $\leq$ 3mg.L^{-1} ($DWCl_3$)

chlorinated deionized water with a free residual chlorine $\leq$ 5mg.L^{-1} ($DWCl_5$)

Treatments were replicated three times

In each treatment the following fertilization was made in each pot:

. 1.0 g Nitrogen
. 1.0 g Phosphorus (P_2O_5)
. 1.0 g Potassium (K_2O)
. 17.0 g Calcium carbonate (in order to increse the soil pH to 6.5)

Fertilization was made before sowing by the addition of an ammonium nitrate solution, potassium dihydrogen phosphate and potassium chloride.
It was applied 0.5g of nitrogen before sowing and the remaining (0.5g) after the second cut on 92-6-29.

Table 4 - Amount (mg) of N, P (P_2O_5) and K added into soil due to wastewater irrigation

Treat./ Nut.	N	P_2O_5	K
WWCl1	1357	104	364
WWCl3	1417	110	377
WWCl5 1263	94	350	

Table 4 shows the amount of nutrients added into soil due to wastewater irrigation. The sowing was done on the 92-4-21 by the application of 2.0g seed to each pot.
Three cuttings in the ryegrass were made when plants were approximately 30cm high. Forage production was evaluated through the weight obtained after drying each cutting in a stove at a temperature of 50°C.
After the last cuttings of ryegrass the soil of each pot was taken out, homogeneized and a soil sample was taken for laboratory analysis.

STATISTICAL DATA ANALYSIS

The experimental design was completely randomized. The data analysis was performed in the statistical package Statgraphics 5.0, by the analysis of variance using the linear fixed additive model, incomplete and bifactorial, for the folowing tratments: $WWCl_1$, $WWCl_3$, $WWCl_5$, $DWCl_1$, $DWCl_3$, $DWCl_5$. For the treatments irrigated only with deionized water we have done also a monofactorial analysis of variance.
The multiple mean comparisions were made by the Tukey test, with a probability of type I error of 5% ($P \leq 0.05$).

RESULTS AND DISCUSSION

4.1 Forage yield

The irrigation with chlorinated wastewater improved the yield in each cutting ($P \leq 0.001$) Table 5.

Table 5 - Dry matter yields (g) of ryegrass in three cuttings

Treat./cuttings	1	2	3	Total
Water				
DW	11.1	11.0	9.6	31.7
WW	14.3	19.1	20.5	53.8
Significance	***	***	***	***
Chlorine				
Cl1	12.2	15.5a	14.1b	41.8b
Cl3	13.4	15.0ab	15.5a	43.8a
Cl5	12.5	14.6b	15.5a	42.6ab
Significance	ns	*	***	**
Water x Chlorine				
WWCl1	14.1	19.0	19.8	52.9
WWCl3	14.8	19.2	20.9	54.9
WWCl5	13.9	19.0	20.8	53.7
DWCl1	10.4	11.9	8.4	30.7
DWCl3	11.9	10.7	10.1	32.7
DWCl5	11.1	10.3	10.2	31.6
Significance	ns	*	ns	ns
(+) MDS (2)		0.91		
(+)MDS (3)		1.112		

(+)the critical value of Tukey

The wastewater irrigation showed some advantages to the forage yield, mainly because it is a rich source of nutrients, having the same effect as a continuous fertirrigation with a diluted concentration of nutrients, according to what Neilsen *et al* (1989) reported. The soil pH level in the treatments irrigated with chlorinated wastewater was higher than in the treatments irrigated with chlorinated deionized water (Table 6). This fact suggests better conditions to the bioavailability of nutrients.
The effect of chlorine level on irrigation water in the forage yield was not very significant in this experiment. The results show however that there was not a disadvantageous effect.

4.2 The influence of the use of chlorinated wastewater in some soil characteristics

The irrigation with chlorinated wastewater affected significantly ($P \leq 0.01$) the organic matter in the soil (table 6), which is lower than the level of the treatments irrigated with chlorinated deionized water.

Table 6 - Organic matter; pH (H_2O), N-Nk e N-NO_3^- values in the soil irrigated with chlorinated wastewater and chlorinated deionized water

Treat.	pH (H_2O)	OM (%)	(1)N-Nk	(1)N-NO_3^-
Water				
DW	7.1	1.27	746	0.6
WW	7.3	1.16	724	0.957
Significance	*	**	ns	***
Chlorine				
Cl1	7.2	1.26	722ab	0,60a
Cl3	7.1	1.20	710b	0.45ab
Cl5	7.2	1.19	773a	0.40b
Significance	ns	ns	*	*
Water xChlorine				
WWCl1	7.3	1.22	655	1.19
WWCl3	7.1	1.10	704	0.89
WWCl5	7.4	1.15	814	0.79
DWCl1	7.2	1.29	790	0.00
DWCl3	7.0	1.30	716	0.00
DWCl5	7.1	1.22	732	0.00
Significance	ns	ns	**	*
(+) MDS (2)			71.64	0.21
(+) MDS (3)			87.68	0.26

(1) $mg \cdot kg^{-1}$; (+)the critical value of Tukey

We think that this fact is due to a more intensive biological activity in the soil irrigated with wastewater which led to a higher mineralization of organic matter in these treatments. We cannot forget that in spite of disinfection, wastewater remains with more microrganisms than deionized water and it also has more nutrients which allows a higher biological activity in the soil. The experiment was carried out in springtime with a good temperature for this activity.

If we compare the organic matter level in the soil at the beginning of the experiment and at the end we verify that in the treatments irrigated with chlorinated wastewater this level was lower and in those irrigated with chlorinated deionized water it did not change.

In table 6 we may observe that the level of free residual chlorine does not seem to affect the level of organic matter in the soil. In this table we may observe also that irrigation with wastewater did not significantly affect the level of Kjeldahl nitrogen in the soil. We observe also that the interaction between the type of water and the level of chlorination used in the experiment is significative ($P \leq 0.01$). When irrigation is done with wastewater chlorination leads to an increase in the level of Kjeldahl nitrogen in the soil. The treatments irrigated with wastewater disinfected with $5 mg.L^{-1}$ of free residual chlorine, show levels significantly higher than the other two levels used in chlorination. However, in the treatments irrigated with deioniozed water chlorination did not seem to affect significantly the Kjeldahl nitrogen in the soil (Tables 6 and 7).

Table 7 - Organic matter; pH (H_2O), N-Nk and N-NO_3^-values in the soil irrigated only with deionized water

Treat..	pH (H_2O)	OM(%)	(1)N-N_k	(1)N-NO_3^-
DWCl0	7.1	1.17	716	1.42a
DWCl1	7.2	1.29	790	0.00b
DWCl2	7.0	1.22	773	0.00b
DWCl3	7.0	1.30	716	0.00b
DWCl5	7.1	1.22	732	0.00b
Significance	ns	ns	ns	**

(1)$mg \cdot kg^{-1}$

As far as the nitrates level of the soil are concerned (Table 6) irrigation with wastewater induced to a significant ($P \leq 0.001$) increase, caused by the nitrogen level of wastewater (Table 2). The plants assimilated only 64% of the total nitrogen introduced in the soil by fertilization and irrigation with wastewater (this value is based on the total nitrogen added into soil due to wastewater irrigation -Table 4 - and fertilization and the amount of the nitrogen assimilated by the plants -Table 8 -).

Table 8 - Amount of the nitrogen assimilated (mg) by the plants irrigated with wastewater*

Nut/Treat.	WWCl1	WWCl3	WWCl5
N	1510.4	1578.2	1413.6

* - The values are the result from the product of the forage yield (Table 5) and the nitrogen content.

The nitrogen in excess might be leached to groundwater or superficial waters (since it has neither physical nor chemical retention in the soils). It may cause pollution problems with disastrous effects both on human and animal health. We emphasize the relevance of the accurate planning of fertilization in the wastewater irrigated areas with the objective of a prevention in the nitrates pollution and to a more economical use of fertilizers (Marecos do Monte,1989; Power e Shepers,1989; Tamburino e Barbagallo, 1989).
We may also observe (table 6) that chlorination leads to a decrease in the level of nitrates in the soil. The treatments irrigated with disinfected wastewater with $1 mg.L^{-1}$ of free residual chlorine shows a significant level of nitrates which are higher than those in the treatments with 3 or $5 mg.L^{-1}$ of free residual chlorine. This aspect is more evident when we only consider the treatments irrigated only with deionized water. As we may see in table 7, in the treatments where chlorination was made the content of nitrates in the soil is almost zero, while in the treatments without chlorination the level of nitrates in the soil is of $1.42\ mg.Kg^{-1}$. This result suggests that nitrification was affected by water chlorination (by the free residual chlorine, which seems to have a bactericide effect also on some microrganisms in the soil, namely in the nitrification bacteria). In the treatments irrigated with chlorinated wastewater this aspect is not so relevant due to the fact that wastewater itself is a source of nitrates .
As far as the data levels of the Kjeldahl nitrogen and nitrates in the soil are concerned, we may think that chlorination inhibits microrganisms activity in the soil, specially the nitrification process.
As it was mentioned before, the organic matter content in the soil was neither significantly affected by chlorination nor by the amount of chlorine used in the disinfection. However, it was observed that in the treatments in which wastewater was used there was a significant decrease in the organic matter content. This fact seems to suggest that not all the soil microbial activity was affected.
The nitrogen content in the soil (organic, ammonium and nitric) suffered a significant change. With the increase of the amount of free residual chlorine used in the disinfection of the wastewater, an increase in the organic and ammoniacal nitrogen content in the soil was observed. This leads to the conclusion that the microbial activity which is responsible for the mineralization of the organic nitrogen and nitrification was affected by chlorination (specially by the higher amount of free residual chlorine used). Therefore, the increase of the organic and ammoniacal nitrogen in the soil (in the treatments in which wastewater was used) is due both to a decrease in some microbial activity and to the nitrogen content of wastewater (table 2).

The nitrates content in the soil also decreased significantly both with chlorination and with the increase of free residual chlorine. This fact supports the above mentioned hypothesis that chlorination affects significantly the soil microbial activity, namely nitrification. This can be observed in the treatments irrigated with chlorinated deionized water only.
The soil microbial activity is necessary to soil fertility, since it is, among other aspects, responsible for the nutrients recycling, transforming them in mineral forms which can be assimilated by plants. Since chlorination affects microbial activity, and specially one of the most important stages of nitrogen mineralization such as nitrification, it may have the following agronomic consequences: on the one hand it may be harmful to soil fertility, on the other hand it may contribute to decrease the pollution risks by nitrates. In this experiment it was not possible to evaluate whether the soil microbial activity on the whole was affected. Therefore, in our opinion, chlorinated wastewater must be used in irrigation with the lowest level of free residual chlorine necessary to the disinfection and chlorination must be carefully supervised.

CONCLUSIONS

The chlorination of wastewater used in irrigation reduce the risks of the transmission of diseases related with the biological characteristics of this water. However, the data obtained suggest that chlorination affects also the microbial activity in the soils, namely the nitrification process. So, when chlorinated wastewater is used in irrigation it must be used the lowest level of free residual chlorine necessary to the disinfection and always under a rigorous control.

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