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Impact of raw and purified wastewater reuse from the Dar El-Gueddari treatment plant on the soil

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Abstract

The study has been carried out at two experimental sites. It aims to assess the impact of the reuse of raw wastewater, purified and diluted with conventional water on the physicochemical quality of soils compared to irrigated soils with conventional drilled water and non-irrigated soil. The obtained results show that the electrical conductivity *EC* and sodium gradually increase in all the plots irrigated with wastewater. Additionally, a slight increase in the pH levels at the first site and a slight decrease in the second site was seen, but at both sites the soils remained alkaline. The infiltration rate of water slide decreases in relation to the amount of irrigation, especially in plots irrigated by raw and treated wastewater. For the same plots, the values of organic matter increased, and the values obtained for the exchangeable sodium percentage (ESP) became high in the third year and reached 17.0% and 16.7% respectively.

Key words: *dilutions, electrical conductivity, infiltration, organic matter, pH, treatment plant, wastewater irrigation*

INTRODUCTION

All over the world, water resources have become increasingly scarce due to population growth and industrial and agricultural development. For this reason, the development of wastewater in agriculture has become an essential component in the policy of integrated management of water resources, particularly in countries with a water deficit [SCOTT *et al.* (ed.) 2004]. Indeed, these types of waters can present advantages for agriculture thanks to their fertilizing values and nutritive elements necessary for the growth and the improvement of the yields of the cultures [GATTA *et al*. 2016; HBAIZ *et al*. 2014; URBANO *et al*. 2017]. In addition, their reuse gives an opportunity for the protection of the environment against the silting phenomenon, this protection manifests when wastewater is used in irrigation instead of variously in rivers and lakes [HANJRA *et al*. 2012]. Moreover, in the short term, this practice does not have a significant impact on changes in physicochemical parameters. On the contrary, long term irrigation by wastewater can bring significant quantities of salts such as: sodium, chlorides, and calcium, which are responsible for the problems of salinity and sodicity [ABEGUNRIN *et al*. 2016; TARCHOUNA *et al*. 2010].

In addition, the contributions of suspended or dissolved matter, microorganisms, and metallic pollutants, can clog the soil pores and cause a strong reduction in the capacity of water infiltration in the soil [CHAOUA *et al*. 2019]. This disturbance of the soil permeability leads to an increase in the load loss and mainly affects the surface soil part [DING *et al*. 2019; DJEDIDI, HASSEN 1991]. Other studies have linked the clogging of the soil not only to the quality of the water but also to the nature of soil and irrigation practice, according to them the problem becomes acute in clay soils irrigated in a gravitational manner [BHARDWAJ *et al.* 2007; MOLLE *et al*. 1998]. The contamination of groundwater, in particular free water tables, remains among the most important potential drawbacks of this practice. For this reason, the wastewater must be carefully managed, monitored, well controlled and must meet the specifications for the required quality.

In the region of Dar El Gueddari in Morocco, agriculture is one of the main development areas of the region. Indeed, the growing need and demand for water in the face of the cost of withdrawing groundwater, pushed the residents of the wastewater treatment plant (WWTP) from time to time to resort to using wastewater from the Dar El Gueddari WWTP, particularly in dry seasons, with intensive uncontrolled reuse and accompanied by a lack of knowledge of the risks of this practice on the physicochemical quality of the soil (infiltration, salinization, alkalinization). In this work we studied the impact of wastewater irrigation on the soils of two sites and sought the optimal conditions to minimize this impact through dilutions with conventional waters.

MATERIALS AND METHODS

GENERAL DATA ON THE SITE

Our study took place in Dar El Gueddari, a city located in the Gharb plain in Morocco. The study area climate is humid to semi-arid with a temperate winter; average annual precipitation is around 450 $mm \cdot y^{-1}$ and is hot, with temperatures reaching up to 45°C during summer [ABH 2018]. Domestic wastewater is collected and transferred through a pumping station at the WWTP, which is of the natural lagoon type with secondary treatment (anaerobic basin + optional basin). The treated wastewater is discharged into the R'dom canal, reused in agriculture, and often mixed with the water from the Sebou River.

EXPERIMENTATION SITE

The study took place on two experimental sites. At the first site, the experimental plot implemented includes six experimental units in the form of lysimetric tanks of 5 m^2 each and 1 m deep, the bottoms are lined with a gravel bed and a drainage system for excess irrigation water. In this experiment, each treatment is done in two repetitions.

The plot irrigation method (P*i*) is gravitational as follows:

– P1 = irrigation by drilling water only (control),
– P2 = irrigation by drilling water + mineral fertilizer (N, P, K),
– P3 = irrigation with raw wastewater,
– P4 = irrigation with purified wastewater,
– P5 = irrigation with a mixture of 50% drilling water and 50% raw wastewater,
– P6 = irrigation with a mixture of 50% drilling water and 50% purified wastewater.

To guarantee the results reliability and to keep only the effect of the irrigation water on the quality of the soil, it is necessary to make homogeneous and uniform in the first site all the operating conditions such as the irrigation water volume, the irrigation mode and time, the areas, and the initial soil quality.

The second site is taken as a complementary site. For this purpose, three plots of 0.8 ha each have been sampled:

– S1: plot taken as reference, is at rest and closed since 1992
– S2: plot intensively irrigated since 2007, by the water taken from the canal immediately downstream from the WWTP discharge, and which is often treated wastewater mixed with the waters of the Sebou River;
– S3 plot irrigated for the first time in 2016, only by treated wastewater;

the irrigation of the second and the third plots is done in a gravity-fed manner.

IRRIGATION WATER

The physicochemical parameters of the irrigation waters which are considered during this experiment are the pH, electrical conductivity (*EC*), the chlorides, the sodium, the bicarbonates, the chemical oxygen demand (*COD*), the biochemical oxygen demand over five days (BOD_5), the suspended matter (SM), the dry residue and the sodium adsorption ratio (*SAR*).

Sampling is carried out twice a season. All samples, which are spot types at the irrigation time, are taken in polyethylene bottles. The conditions of sampling, fixing and storage according to standard DR – 09-04 of the Centre of Expertise in Environmental Analysis of Quebec (Fr. Centre d'Expertise et Analyse Environnementale du Québec) (EAEQ) and the rules of good practice of the National Office of Drinking Water – Morocco (Fr. Office National de l'Eau Potable-Maroc) (ONEP) [CEAEQ 2004; ONEP 2003], are well respected. Temperature, pH, dissolved oxygen, and *EC*, are measured in situ. Other parameters such as *COD*, BOD_5, SM, sulphates, sodium, chlorides, and dry residue, are determined in the laboratory.

Temperature and the pH were determined by a CONSORT C831 type pH meter [NM ISO 10523: 2012]. BOD_5 was determined by the OxiTop method [ISO 5815-2:2003]. *COD* was determined by spectrophotometer at a wavelength of 420 nm after oxidation with potassium dichromate. SM was determined by filtration. Sulphates, sodium, chlorides and potassium have been determined by the continuous flow method. The Table 1 summarizes the average values of the different types of irrigation water.

SOIL

The physicochemical characteristics of the soils were determined on samples made up of a mixture of several earth cores collected on a horizon 0–30 cm, except for the *EC* samples which have been collected on two horizons 0–30 cm and 30–60 cm. The analyses were carried out at the soil analysis laboratory of the Regional Office for Agricultural Development – Morocco (Fr. Office regional de mise en valeur Agricole du Garb-Maroc) (ORMVAG) and the Moroccan Agriculture Laboratory (Laboratoire Marocain pour l'Agriculture) (LABOMAG).

Table 1. Physicochemical characteristics of irrigation water

Parameter	Unit	RWW	TWW	RWW + DW	TWW + DW	WWTP downstream	DW	Irrigation limit values
pH		7.77	8.08	7.87	7.09	8.0	7.50	6.5–8.5
EC	$dS \cdot m^{-1}$	3.37	2.87	1.94	1.61	1.66	0.615	3
SM	$mg \cdot dm^{-3}$	408.0	130.0	210	116.1	34.25	1.2	–
COD	$mg \cdot dm^{-3}$	985.0	380.0	493.4	182.0	53	10	
BOD_5	$mg \cdot dm^{-3}$	375.0	117.0	189.7	59.0	20.8	5.3	
Sodium	$mg \cdot dm^{-3}$	502.42	435.60	284.4	255.5	55.1	74	–
Chloride	$mg \cdot dm^{-3}$	587.9	489.0	346.1	212.75	151.8	99.4	
Bicarbonate	$mg \cdot dm^{-3}$	1096.5	911.83	675.4	582.29	366.5	256.2	–
SAR		9.14	7.65	6.02	5.8	1.75	1.2	9
Dry residue	$g \cdot dm^{-3}$	2.54	1.34	1.28	0.91	0.97	0.3	2

Explanations: RWW = raw wastewater; TWW = treated wastewater; WWTP = wastewater treatment plant, DW = drilling water, *EC* = electrical conductivity, SM = suspended matter, *COD* = chemical oxygen demand, BOD_5 = biochemical oxygen demand over five days, *SAR* = sodium adsorption ratio.
Source: own study.

Table 2. Initial soils physicochemical characteristics

Parameter	Unit	Value in site	
		1	2
Equivalent humidity		32.90 ± 0.86	32.41 ± 0.50
Clay (C)	%	66.53 ± 0.12	57.62± 0.46
Thin silts (TS)	%	12.33± 0.31	30.40 ± 0.83
Thick silts (TKS)	%	16.50 ± 0.08	5.30 ± 0.650
Thin sands (TS)	%	2.67 ± 0.05	6.20 ± 0.50
Thick sands (TKS)	%	21.10 ± 0.08	1.17 ± 0.21
Total limestone ($CaCO_3$)	%	10.92 ± 0.17	14.50 ± 0.24
Active limestone	%	6.80 ± 0.22	8.23 ± 0.19
Organic matter (OM)	%	1.9 ± 0.01	2.27 ± 0.06
C/N		9.91	9.28
Water pH		8.07 ± 0.01	8.63 ± 0.06
KCl_{pH}		7.12 ± 0.02	7.47 ± 0.05
Electrical conductivity (*EC*)	$dS \cdot m^{-1}$	0.2 ± 0.01	0.09 ± 0.01
Potassium	$mg \cdot kg^{-1}$	477.203 ± 11.04	333 ± 5.89
Sodium (Na_2O)	$mg \cdot kg^{-1}$	379.00 ± 54.49	274.00 ± 25.94
Magnesium (MgO)	$mg \cdot kg^{-1}$	872.77 ± 14.40	1794.33 ± 99.95
Calcium (CaO)	$mg \cdot kg^{-1}$	8432.00 ± 39.73	5218.87 ± 207.75
Ammonium ($N\text{-}NH_4$)	$mg \cdot kg^{-1}$	21.07 ± 0.21	25.42 ± 1.05
Nitrate ($N\text{-}NO_3$)	$mg \cdot kg^{-1}$	140.06 ± 2.86	62.54 ± 1.24
Phosphorus (P)	$mg \cdot kg^{-1}$	13.83 ± 0.24	14 ± 0.06
Chloride (Cl)	$mg \cdot kg^{-1}$	132.55 ± 3.42	41.12 ± 7.03
Sulphate (SO_4)	$mg \cdot kg^{-1}$	122.50 ± 3.93	71.24 ± 3.72
Cation exchange capacity (*CEC*)	$meq \cdot (100\ g)^{-1}$	24.37 ± 0.12	19.64± 0.78
Exchangeable sodium percentage (*ESP*)	%	6.07 ± 0.02	4.34 ± 0.34

Source: own study.

The frequency of soil sampling for pH and *EC* analysis has been in order of three times per season. OM, cation exchange capacity, sodium, and calcium, in the first site were sampled in two occasions, the first was at the beginning of the first season before cultivation, and the second sampling was at the end of the experiment. However, in the second site, they were sampled only once at the end of the third season, whereas soil samples in the second site were collected only once in parallel with the second sampling at the first site.

The soil pH of all the plots was measured with a pH meter in a soil suspension diluted 1/5 with distilled water. The *EC* has been determined on a filtered extract 1/5 (m/v), and the results are corrected at a temperature of 25°C. The phosphorus content was determined by spectrometric determination after extraction of the soluble forms using a sodium hydrogen carbonate solution (Oslen method). Sodium, magnesium, and potassium were extracted with ammonium acetate at pH = 7, and have been determined using an atomic absorption spectroscopy, and the cation exchange capacity CEC was determined by Cobaltihexamine chloride at soil pH.

All the results of the initial soils are illustrated in the Table 2.

RESULTS AND DISCUSSION

IRRIGATION WATER

It should be noted that the contents of the different physicochemical parameters of the raw, purified wastewater and the drilling water are stable and do not undergo significant variations during the three test seasons. The effects of irrigation water on the soil are judged by electrical conductivity (*EC*), sodium, chlorides, and sodium adsorption ratio (*SAR*) [AYERS, WESTCOT 1985].

The results relating to suspended matter (SM), BOD_5, and *COD* for treated wastewater from the wastewater treatment plant (WWTP) are respectively: 130 mg·dm^{-3}, 117 mg·dm^{-3} and 380 mg·dm^{-3}. These values are a little high compared to the standards set by the Moroccan standard for irrigation water [Ministre de l'Equipement 2002]. For raw wastewater these values are also very high, they are around 408 mg·dm^{-3} for suspended solids, 375 mg·dm^{-3} for BOD_5 and 985 mg·dm^{-3} for *COD*. As regards, chlorides, sodium and bicarbonates, they are respectively around 587.9 mg·dm^{-3}, 502.42 mg·dm^{-3} and 1096.5 mg·dm^{-3} for raw wastewater and 489 mg·dm^{-3}, 435.6 mg·dm^{-3} and 911.83 mg·dm^{-3} for purified wastewater.

In both types of water, these values are also very high and exceed the values set by the FAO and the Moroccan standard for irrigation water. These values are reduced through dilution by 50%. The values found downstream of the WWTP release during the study period do not exceed 20 mg·dm^{-3} for BOD_5 and 58 mg·dm^{-3} for *COD* and 34 mg·dm^{-3} in SM.

SOIL

The granulometric analysis of the soil shows that the textures of the first site are of the clay type while the second is of the clay-silt type, with a water retention capacity of 27% for the first site and 23% for the second site.

SOIL pH

For the first site, where the mode and quantity of irrigation water are well controlled, the pH has slightly increased in all the plots irrigated by raw or treated wastewater (Fig. 1). This may be due to the enrichment of the irrigated soils in basic cations and also at the low infiltration speed which favours the accumulation of salts on the surface of the plots. The plots irrigated by the drilled water recorded a stable pH and remained around 8.06.

For site No. 2 and particularly in the intensively irrigated plot since 2007, the pH has decreased slightly compared to the reference soil; it goes from 8.6 ± 0.14 to 8.09 ± 0.03 and still remains moderately alkaline. These results can be explained by the quality of the irrigation water which is diluted by conventional water and the gravity irrigation mode which leads to leaching of the active limestone responsible for the alkalinity.

The total limestone measured is of the order of 11.70 ± 0.24% compared to the reference value which is by means of 14.50 ± 0.59%, in this context a flow monitoring at the head of the pump shows an excessive use of irrigation water which is around 1950 m^3·ha^{-1} for each irrigation, this value exceeds the theoretical value need as stated by the ORMVAG. This reduction is in agreement with another research which links the decrease in pH upon leaching of active limestones responsible for the alkalinity of the soil by irrigation water [SOLÍS *et al*. 2005]. The decrease in soil pH

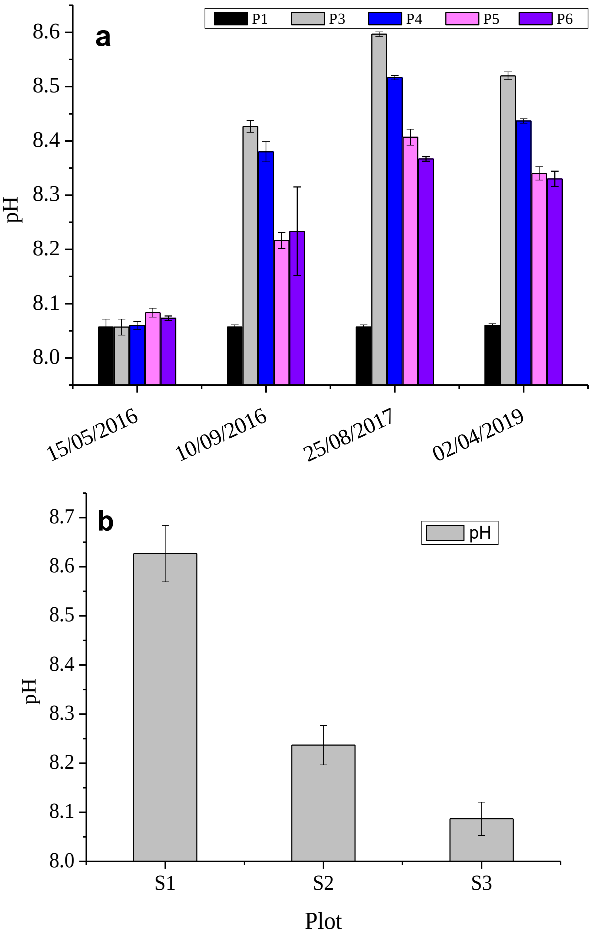

Fig. 1. Evolution of pH in the soils a) site No. 1, b) site No. 2: P1 = control, P3 = plot irrigated with raw wastewater (RWW), P4 = plot irrigated with purified wastewater (PWW), P5 = plot irrigated with a mixture of 50% drilling water and 50% RWW, P6 = plot irrigated with a mixture of 50% drilling water and 50% PWW; S1 = plot taken as reference, is at rest and closed since 1992, S2: plot intensively irrigated since 2007, by the water taken from the canal immediately downstream from the WWTP discharge, and which is often treated wastewater mixed with the waters of the Sebou River, S3 plot irrigated for the first time in 2016, only by treated wastewater; source: own study

is not always associated with a variation in the carbonate content, but it can also be linked to the oxidation of organic matter (OM) and the nitrification of ammonium in the soil [ABD-ELWAHED 2019; CURTIN *et al*. 2016].

MONITORING OF SOIL SALINITY

The monitoring of soil salinity during this study is illustrated in Figure 2. The curves show that the *EC* increases with the amount of irrigation especially in the surface horizons (0–30 cm) of the plot irrigated with raw and treated wastewater. This rise is probably linked on the one hand to the quality of the water loaded with salts, and on the other hand, to the impact of very intense evapotranspiration during the summer period. The values given by the ORAMVAG are between 487, 20 mm and 602.38 mm during the three months of June, July and August in the years 2016, 2017 and 2018.

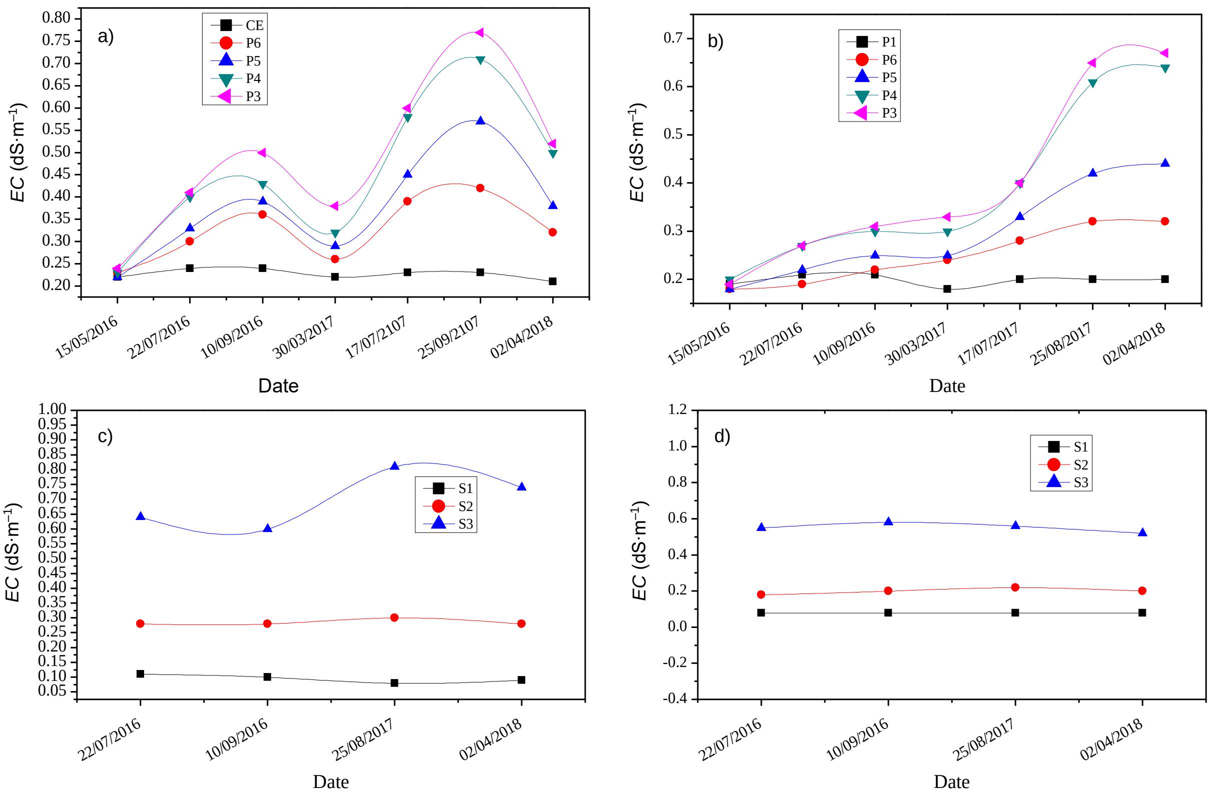

Fig. 2. Evolution of electrical conductivity (*EC*) in site No. 1: a) horizon 0–30 cm, b) horizon 30–60 cm and in site: No. 2: c) horizon 0–30 cm, d) horizon 30–60 cm; explanations as Fig. 1; source: own study

DROUBI *et al*. [1979], reported that the influence of temperature can be seen, depending on the intensity of an evaporation action and a deposit of salts from irrigation waters in the upper layers of the soil. This phenomenon is interesting when the areas are well levelled and the topography is favourable [DROUBI *et al*. 1979; LIU 2019]. On the other hand, the leaching of the salts deep causes an increase in the *EC* in the second level 30–60 cm compared to the control. Similarly, in the same vein, studies carried out on the reuse of wastewater in different regions have reported an increase in the conductivity of plots irrigated by wastewater compared to the initial soil values [MOUHANNI *et al*. 2012; RECHACHI 2017]. During the winter period, the *EC* values are reduced and this may be linked to the salts leaching from rainwater. During this study phase the annual precipitation is around 474 mm in 2017 and 493 mm in 2018.

We noted that the irrigation with wastewater resulted in an accumulation of salts in the soil compared to the control. The deepest horizons see their conductivity increase due to leaching of the salts responsible for the increase in conductivity.

EVALUATION OF THE PURIFYING POWER AND CLOGGING OF THE STUDIED SOIL

This evaluation is carried out using a monitoring of the physicochemical quality of the irrigation water and percolated water from the lysimeter, during our experiment.

The obtained values from SM, BOD_5 and *COD* of percolated water (Tab. 3), show that the soil has retained a large part going up to 89.3% of SM, 85.4% of BOD_5 and 86.3%

Table 3. Percentage reduction in suspended matter (SM), chemical oxygen demand (*COD*) and biochemical oxygen demand over five days (BOD_5)

Parameter	Value in initial water	Value in percolated water	Abatement rate (%)
SM, mg·dm^{-3}	340	37.8	89.3
COD, (mg O_2)·dm^{-3}	860	117.43	86.3
BOD_5, (mg O_2)·dm^{-3}	368	55.4	85.4

Source: own study.

of *COD*, this means that irrigation by wastewater leads to clogging of the soil.

To ensure the reliability of these results, we also made field observations concerning soil clogging, by measuring the persistence time of a sheet of water on the surface of each plot. The results (Fig. 3) of these observations show that the time of persistence increases slightly with the amount of irrigation in the irrigated plots with raw and treated wastewater. Such a decrease in the hydraulic conductivity of soils irrigated using wastewater, was observed by several authors, they have agreed that this decrease varies according to the quality of the irrigation water, the soil intrinsic properties, and the irrigation practice [BARDHAN *et al*. 2016; BHARDWAJ *et al*. 2007; TARCHOUNA *et al*. 2010].

DOSAGE OF SOLUBLE IONS

To assess the impact of irrigation water on the chemical composition of the soil, we analysed the chemical elements which are responsible for salinity such as calcium, magnesium, sodium and chlorides. The results illustrated in

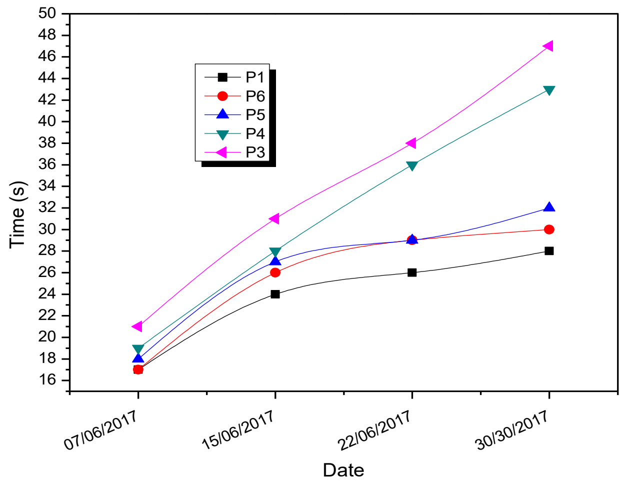

Fig. 3. Persistence time of a blade of water on the surface of each plot – site No. 1; explanations as Fig. 1; source: own study

Figures 4a, b, c, d, represent the contents of the aforementioned ions the 0–30 cm layer of the soils studied. The high sodium and chloride contents are found in the plots irrigated by raw wastewater with values respectively 781.57 ± 5.39 mg·kg^{-1} and 184.20 ± 1.5 mg·kg^{-1} followed by treated wastewater which are respectively of the order of 727.49 ± 1.13 mg·kg^{-1} and 178.4 ± 0.78 mg·kg^{-1} of soil.

The plots irrigated by purified wastewater diluted with drilling water have average sodium contents of the order of 383.77 ± 5.39 mg·kg^{-1}. The calcium values registered a decrease in all the plots irrigated by wastewater, which are raw, purified or diluted, with a rate of 12 and 13% respectively for the plots irrigated by raw wastewater and treated wastewater. The potassium has not recorded any significant variation and remains around the initial value.

The quality of the irrigation water which is rich in salts, and the temperatures recorded during the study phase and which are on average 35°C, and the texture of the soil which is of a clayey nature all contributed to the salt accumulation in the surface layer. On the other hand, intensive irrigation by laden waters poses a serious problem by the formation of a surface crust which prevents the penetration of water and air into the soil [ABD-ELWAHED 2019]

Looking at the exchangeable sodium percentage (*ESP*), the values found in the plots irrigated by raw and treated wastewater from site No. 1, are respectively 17 and 16.7% compared to the initial soil (*ESP* = 6.07%). These values exceed the 15% threshold which is initially considered to be the critical level which affects the soil stability [RICHARDS (ed.) 1954].

ORGANIC MATTER OM

During this experimental phase, the organic matter (OM) of the soil in the first site recorded a small increase in all the plots irrigated by the treated wastewater they do not exceed the value of 2.1% with the exception of the plots

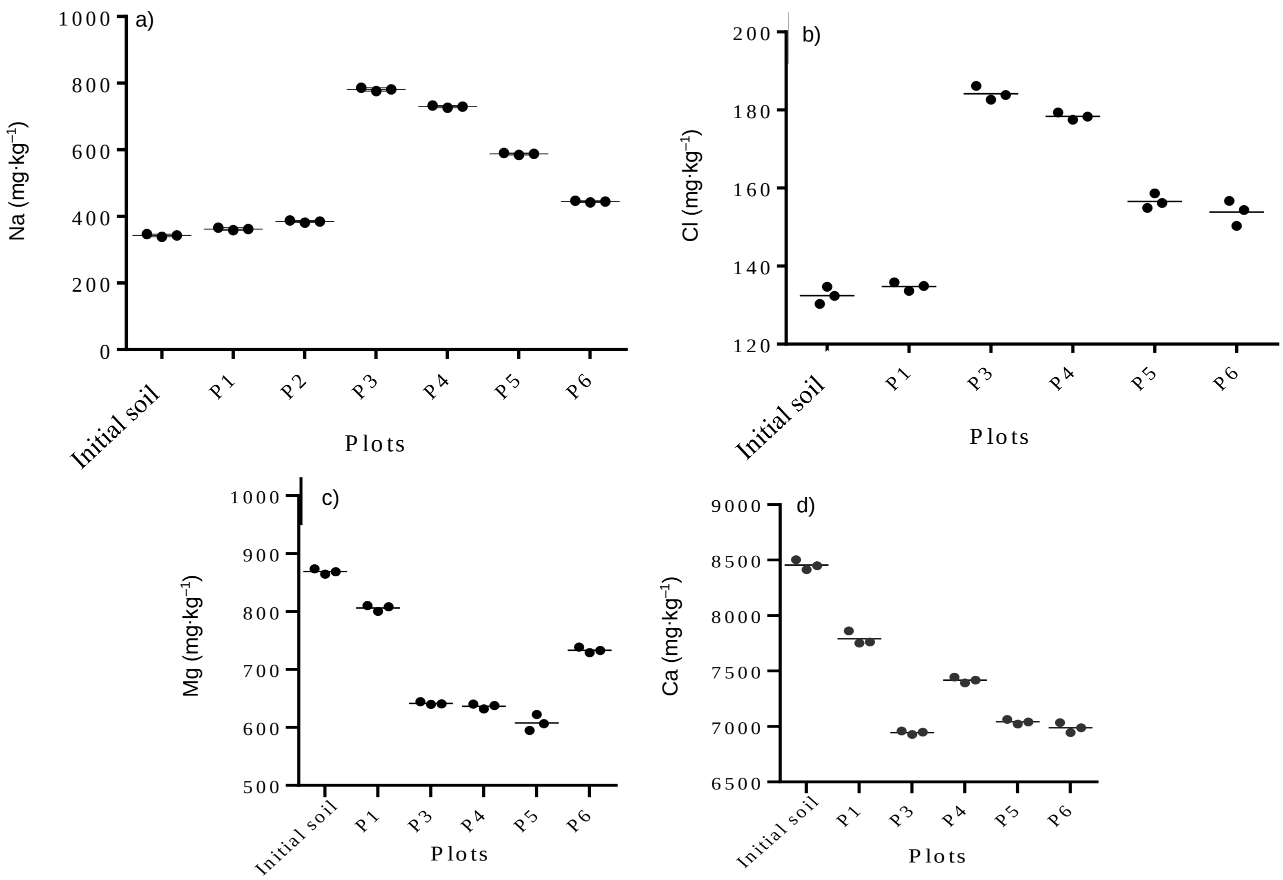

Fig. 4. Evolution of soluble ions in site No. 1: a) sodium, b) chloride, c) magnesium, d) calcium; explanations as in Fig. 1; source: own study

irrigated by the raw wastewater where the values found are between 2.3 and 2.43%. This increase is linked to the quality of raw wastewater which is rich in livestock waste sent to the WWTP by the same urban wastewater collector. The control plot experienced a slight decrease of 0.05% compared to the initial value. Similarly, SINGH *et al*. [2012] found that irrigation by wastewater contributes to a large improvement in soil organic carbon compared to irrigation by well water.

In the second site, a plot intensively exploited since 2007 recorded a decrease of 0.58% compared to the value found in the reference plot and which is 2.31%. This decrease is probably linked to the irrigation method practised and the quality of the irrigation water, which is diluted from time to time by the waters of the Sebou River. On the other hand, the OM of the plot irrigated since 2016 by the treated wastewater remains a little stable.

In this regard SÀNCHEZ-GONZALEZ *et al*. [2017] have shown that irrigation by wastewater compensates for the loss of OM by increasing the root biomass of plants which, by its lignin content, contributes to the increase in stocks of soil organic carbon. But excessive irrigation and mismanagement of crop residues are responsible for the loss of OM [BADRAOUI *et al*. 2000; N'GUESSAN *et al*. 2019].

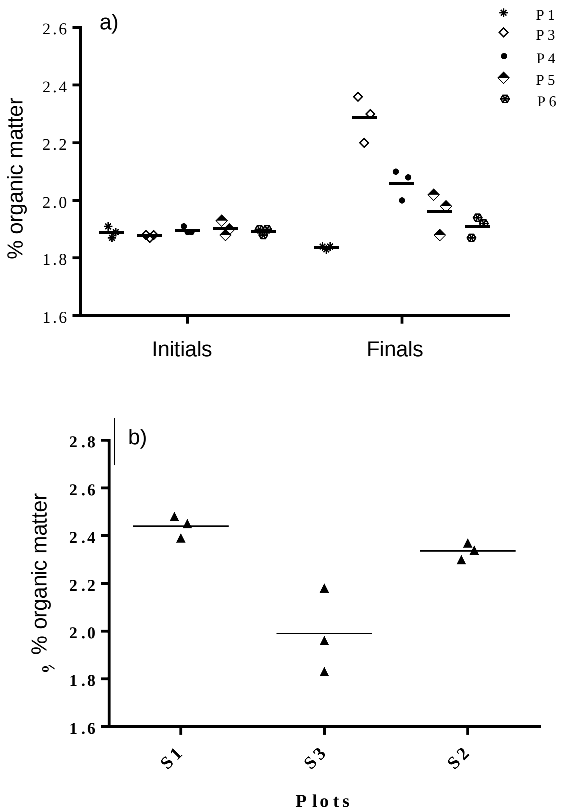

Fig. 5. Evolution of organic matter in: a) site No. 1, b) site No. 2; explanations as in Fig. 1; source: own study

CONCLUSIONS

It appears at this level of study that wastewater irrigation impacts salinity, electrical conductivity (*EC*), pH, exchangeable sodium percentage (*ESP*) and soil permeability. Indeed, the soil *EC* increases more at the surface than at the depth, at the end of the study the values recorded in the plot irrigated by raw wastewater (RWW) touch an average value of 0.77 $dS \cdot m^{-1}$ in the surface layer of 0–30 cm in comparison with the control plot whose *EC* persists around 0.23 $dS \cdot m^{-1}$. Under the percolating effect of the irrigation water, the value of the *EC* gradually increases from 0.19 $dS \cdot m^{-1}$ at the start of the experiment to 0.67 $dS \cdot m^{-1}$ at the end of this study. As a result, the quantity of salts accumulated in the soil, which results in the value of *ESP* and which reaches critical levels above 15%, is linked to the quantity and quality of irrigation water, to intrinsic properties. From the soil which are clayey type and to the climatic conditions of the region which are dry with high evapotranspiration. Indeed, the dilution of the wastewater with conventional good quality water reduced the impact and was one solution to maintaining good soil quality. In contrast, the *EC* was reduced to almost 40% in plots irrigated by diluted RWW and diluted PWW. The average values obtained are respectively 0.57 $dS \cdot m^{-1}$ and 0.42 $dS \cdot m^{-1}$. On the other hand, irrigation by wastewater has enriched the soils by OM despite the short duration of the study, in plot irrigated with RWW the average value of this parameter is around 2.3%.

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