

The Effect of Purified Wastewater on the Physicochemical Properties of Agricultural Soils in Chaouia in Morocco

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ABSTRACT

The aim of this study was to assess the impact of the reuse of purified wastewater from the wastewater treatment plant in the city of Settat on the physicochemical quality of agricultural soils compared to the agricultural soils irrigated by rainwater in the region of Chaouia in Morocco. The results obtained showed that despite the great fertilizing value of the purified wastewater, a slight increase in salinity was noted; they also reveal a significant difference in pH. The accumulation of sodium, total limestone and active limestone in the soil increased significantly in the soils irrigated by treated wastewater; in contrast, calcium increased significantly in the soils irrigated by rainwater. No significant differences were recorded for humidity, electrical conductivity, ammonium, nitrates, phosphorus, potassium, organic matter, total nitrogen or cation exchange capacity.

Keywords: Purified wastewater, rainwater, treatment plant, agricultural soils, salinity.

INTRODUCTION

Due to its hydro-climatic context, Morocco is subject to significant water stress. This latter is exacerbated by climate change which manifests itself in the form of fluctuating precipitation or the occurrence of dry years. These conditions lead many farmers to use raw wastewater for irrigation due to its richness in organic matter and nutrients (Kao et al., 2007). Indeed, the use of untreated or poorly treated wastewater can cause several problems such as the consumption of agricultural products contaminated by the pollutants contained in wastewater, the accumulation of heavy metals in the soil and plants and the possible environmental dispersion of macro and micronutrients (Gatta et al., 2020). Therefore, within the framework of the strategic water management axes, the mobilization of unconventional

water resources is encouraged and in particular the reuse of purified wastewater for irrigation.

Morocco began to attach importance to wastewater treatment relatively late. The main function of wastewater treatment is to avoid the harmful effects on receiving environments and on receiving surfaces, large inputs of nutrients and organic and inorganic pollutants contained in wastewater (Grundmann and Maaß, 2017). The increase in the rate of wastewater treatment in Morocco has been noted owing to several new functional treatment plants. The wastewater treatment plant in the city of Settat, which is a natural lagoon-type plant, is among the projects carried out in this context. The community of Settat is located in a traditionally agricultural region of Morocco. However, crops are highly dependent on rainfall, given the absence of permanent rivers and the prohibitive cost of establishing sufficiently deep boreholes.

The comparison of the wastewater lagoon treatment process with other channels already tested in Morocco, has shown that natural lagooning remains the most widespread technique, because it requires low running and operating costs as well as little technical expertise. The wastewater treatment plant in the city of Settat produces nearly 5 million cubic meters of purified water per year. In the aforementioned context, this easily accessible purified water represents a precious water resource for the farmers of the agricultural perimeter located downstream from the purification station. Indeed, the peculiarity of this region is the absence of psychological barrier linked to the use of purified wastewater by most farmers in this region, and this is due to the scarcity of water on the one hand, and old practices of using raw wastewater by certain farmers on the other. With the aim of encouraging the use of treated wastewater without noticeable damage to the health of farmers and consumers of agricultural products, this study is part of the paradigm concerning the reuse of treated wastewater from the city of Settat in agriculture. A survey was undertaken by El Kettani et al. in 2006 for the assessment of the risk associated with the use of raw wastewater from the city of Settat for agricultural purposes in connection with *Giardia Intestinalis*, showed that the use of these water in agriculture is responsible for an increased risk of giardiasis. It is also responsible for an increased risk of helminthiasis (El

Kettani, 2006). Another study carried out by Hajjami et al. in 2012 showed that irrigation with raw wastewater in the regions of Settat and Soualem leads to parasitological contamination of irrigated crops. Although purified wastewater has positive effects on the richness of the soil in fertilizing elements, it can also have negative effects, namely the influence on the physicochemical properties of the soil and the salinization of the horizons on its surface (Halimi et al., 2018). Irrigation with treated wastewater can also present a risk to crops which depends on the one hand on the quality of the treated wastewater, and on the nature of the soil cover and cultivation practices on the other (Belaid, 2010). A study which was already carried out by Abou-tammame et al. in 2021 showed that the purified wastewater from the Settat WWTP is classified in category B. The water which belongs to this category can be used for the irrigation of crops, cereals, industrial and fodder, pastures and tree plantations (State Secretariat to the Ministry of Energy, Mines, Water and the Environment, in charge of Water and the Environment, 2007). Several farmers downstream from the wastewater treatment plant in the city of Settat use the purified wastewater from this WWTP for irrigation. This work was carried out with the aim of determining the effect of the purified wastewater from this WWTP on the physicochemical properties of agricultural fields in the Chaouia region in Morocco.

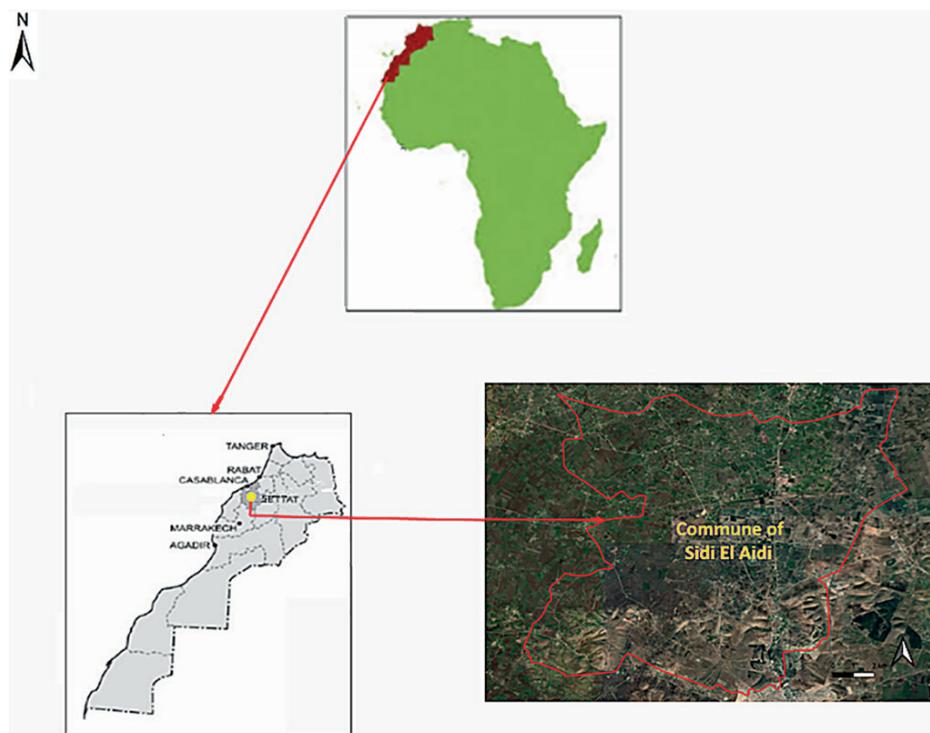


Figure 1. Study site map

MATERIALS AND METHODS

Study site

This study concerned three rural communes, reaching a total of 20 farmer fields located in front of and downstream of the wastewater treatment plant of the city of Settat, which is located about 8 kilometers from the city of Settat, characterized by a semi-arid climate with fairly hot summers (35°C to 45°C) and relatively cold winters (5°C to 15°C) with annual average precipitation of around 350 millimeters (Aboutayeb et al., 2020).

Sampling

The soil sampling was carried out during the second week of January 2021. As it was already mentioned, the study focused on 20 fields, 10 of which are irrigated by purified wastewater and 10 by rainwater (Table 1). The samples were taken from a depth of 0 to 20 cm using an auger while zigzagging the field. These samples were mixed well to form a composite sample, then were bagged and transported to the laboratory. Before the physicochemical characterization, all the samples were dried in an oven, then crushed and sieved through a 2 mm mesh.

Table 1. Characteristics of the fields of the sampled soils

Sample	Community	Cultivation system	Previous cultivation	Current culture	Year of adoption
1	Douar Lewrarka Commune Sidi El Aidi	rainwater	durumwheat	barley	more than 30 years
2	Douar Lewrarka Commune Sidi El Aidi	rainwater	soft wheat	triticar	more than 30 years
3	Douar Ghraba Commune Sidi El Aidi	rainwater	barley	barley	always
4	Douar Ghraba Commune Sidi El Aidi	rainwater	barley	barley	always
5	Douar Wlad Saad Commune Sidi El Aidi	rainwater	alfalfa	alfalfa	always
6	Douar Wlad Saad Commune Sidi El Aidi	rainwater	fallow land	wheat	always
7	Douar Wlad Saad Commune Sidi El Aidi	rainwater	wheat / barley	barley	always
8	Douar Wlad Saad Commune Sidi El Aidi	rainwater	wheat	wheat / barley	always
9	Douar Wlad Saad Commune Sidi El Aidi	rainwater	barley	barley	always
10	Douar Wlad Saad Commune Sidi El Aidi	rainwater	barley	olives	always
11	Douar Wlad Saad Commune Sidi El Aidi	purified wastewater	grains	grains	since 2007
12	Douar Wlad Saad Commune Sidi El Aidi	purified wastewater	alfalfa	alfalfa	since 2007
13	Douar Ghraba Commune Sidi El Aidi	purified wastewater	feed	wheat	more than 15 years
14	Douar Ghraba Commune Sidi El Aidi	purified wastewater	corn	feed	more than 15 years
15	Douar Ghraba Commune Sidi El Aidi	purified wastewater	wheat	feed	more than 15 years
16	Douar Ghraba Commune Sidi El Aidi	purified wastewater	fallow land	alfalfa	always
17	Douar Ghraba Commune Sidi El Aidi	purified wastewater	alfalfa	alfalfa	always
18	Douar Ghraba Commune Sidi El Aidi	purified wastewater	olives	olives	always
19	Douar Ghraba Commune Sidi El Aidi	purified wastewater	corn	alfalfa	always
20	Douar Ghraba Commune Sidi El Aidi	purified wastewater	parsley	alfalfa	always

Soil analysis

In order to assess the reliability of the physicochemical analyses, two measurements were taken for each soil sample. The analyses carried out involved humidity, pH, electrical conductivity, ammonium, nitrates, phosphorus, potassium, sodium, calcium, organic matter, total nitrogen, cation exchange capacity, total limestone and active limestone. Concerning humidity, the soil samples were placed in an oven until they were well dried, and the difference in mass before and after drying, gives the moisture content expressed as a percentage (%). The pH and the electrical conductivity of the soils were measured by a Mettler Toledo type pH meter (China) and a Hanna Instruments type conductivity meter (Romania) (soil/water extracts 1:2 w/v), respectively (McLean, 1983). Ammonium was analyzed by colorimetry where the ammonium from the soil reacts with phenol in the presence of hypochlorite and gives a complex of a blue color. The reading was taken using the absorbance of a Shimadzu (China) type spectrophotometer at a wavelength of 636 nm. The nitrate content was measured by complexation with chromotropic acid using transmittance in a Milton Roy Company (USA) type spectrophotometer at a wavelength of 410 nm (Hadjidemetriou, 1982). The colorimetric method made it possible to determine the phosphorus content using a Milton Roy Company (USA) type spectrophotometer at a wavelength of 882 nm (Olsen et al., 1954). In order to determine potassium (K^+), sodium (Na^+) and calcium (Ca^{2+}), the reading of solutions of soil extract with ammonium acetate was carried out by a flame photometer (Elico, Italy) (Knudsen et al., 1983). Organic matter was determined by using the Walkley and Black method, which is based on titration with potassium dichromate (Walkley and Black, 1934). The total nitrogen content was evaluated by means of the Kjeldahl method (Bremner, 1960) (Büchi, Switzerland); this method comprises 2 steps : the first consists in the digestion of the sample in concentrated sulfuric acid at high temperatures in order to convert the organic nitrogen into mineral nitrogen in ammoniacal form, and the second step is the determination of the ammonium in the extract by titration of NH_4^+ given off by steam distillation (Wang et al., 2017). The cation exchange capacity was determined by saturating the soil with sodium. The latter (Na^+) replaces all the cations present in the

exchangeable part of the soil, then leached with an ammonium acetate solution and determined by using a flame photometer (Elico, Italy). The total limestone was determined by means of the Bernard calcimeter (Duchauffour, 1960) (Bardin, 1967), and the active limestone using the method of Drouineau (1942).

Data analysis

Statistical analysis of the data was carried out using the analysis of variance one way (ANOVA 1 test), which compared the concentrations of each parameter in the soils irrigated by purified wastewater and the soils irrigated by rainwater. The ANOVA test was supplemented by the Tukey test in order to verify the existence of significant differences between the contents of the parameters studied in the 2 types of soil.

RESULTS AND DISCUSSION

Humidity

The results of the studied soils show that the percentage of humidity in the soils irrigated by the purified wastewater varies between 5.71% and 6.98% with an average of $6.15 \pm 0.41\%$, while the percentage of moisture in the soils irrigated by rainwater oscillates between 4.71% and 7.37% with an average of $6.09 \pm 0.73\%$ (Table 2). The means of the 2 soil types are very close to each other, and the average moisture values given in Table 2 show no significant difference between the 2 soil types.

pH

The pH is a very important physical parameter of the soil. It plays a major role in the biological life and in the growth of plants because it influences the availability of nutrients in the soil in a very clear way, and it is affected by various factors, including the supply of fertilizers. The results obtained from the pH analysis show that the pH of the soils irrigated by the purified wastewater from the wastewater treatment plant in the city of Settat varies between 8.5 and 9 with an average of 8.77 ± 0.16 , while the soils irrigated by rainwater have a pH between 8.2 and 8.8 with an average of 8.54 ± 0.2 (Table 2). According to these results and the DIAEA/

Table 2. Results of analysis of the soils irrigated by purified wastewater and the soils irrigated by rainwater

Parametres	Soils irrigated by treated wastewater		Soils irrigated by rainwater		P _{Value}
	Average	Standard deviation	Average	Standard deviation	
Humidity (%)	6.15	0.41	6.09	0.73	0.839
pH	8.77	0.16	8.54	0.2	* 0.014
Electric conductivity (mm hos)	0.26	0.02	0.24	0.1	0.457
Ammonium (mg/kg)	9.62	4.77	20.86	19.44	0.093
Nitrates (mg/kg)	23.17	8.34	22.45	11.25	0.874
Phosphorus (mg/kg)	64.14	43.53	72.72	58.59	0.714
Potassium (mg/kg)	963	321.49	1377	1170	0.295
Sodium (mg/kg)	947	112.25	586	403.38	* 0.014
Calcium (mg/kg)	7003	538.29	8471	887.44	* 0
Organic matter (%)	3.78	0.59	3.69	0.89	0.797
Total nitrogen (%)	0.2	0.03	0.21	0.05	0.763
Cation exchange capacity (meq / 100g)	50.71	21.84	39.13	8.67	0.136
Total limestone (%)	15.65	4.96	5.85	4.47	* 0
Active limestone (%)	8.71	1.14	4.4	1.86	* 0

Table 3. Soil pH classes according to the standards of DIAEA/DRHA/SEEN (2008)

Soil class	pH
Acidic	< 6
Slightly acidic	6 – 6.5
Neutral	6.5 – 7.3
Slightly basic	7.3 – 7.8
Moderately basic	7.8 – 8.5
Alkaline tendency	8.5 – 9
Very alkaline	> 9

DRHA/SEEN (2008) standards, the two types of soil have an alkaline tendency (Table 3), with a slight increase in the pH of the soils irrigated by purified wastewater, compared to the soils irrigated by rainwater. It can be concluded that irrigation with purified wastewater resulted in a slight increase in soil pH, which was also confirmed by Tarchouna et al. in 2010. The results obtained show a significant difference in this parameter ($P_{\text{Value}} < 0.05$).

Electrical conductivity

Electrical conductivity represents the soluble salt content of the soil (Maktouf et al., 2019), and it is most often used for the presentation of the salinity of water and soil. The electrical conductivity of soils irrigated by treated wastewater recorded varies between 0.23 mmhos/cm and 0.32 mmhos/cm with an average of 0.26 ± 0.02 mmhos/cm. For the soils irrigated by rainwater, the electrical conductivity values vary between 0.14 mmhos/cm and 0.44 mmhos/cm with an average of 0.26 ± 0.1 mmhos/cm (Table 2). The results obtained show that the soils irrigated by purified wastewater are fertile soils and belong to the adequate class, while the soils irrigated by rainwater belong to the poor class and may have a probable deficiency in major elements (El Gharous et al., 1995) (Table 4). It can be concluded that the presence of ions (soluble salts) is greater in the soils irrigated by purified wastewater. Although the irrigation of the soils with purified wastewater caused a slight increase in soil salinity, which is in accordance with

Table 4. Classes of electrical conductivity in soils according to El Gharous et al. (1995)

Class	Electric conductivity (mmhos/cm)	Interpretation
Deficient	< 0.01	This soil may be deficient in major elements
Poor	0.1 – 0.24	A major element deficiency is likely
Adequate	0.25 – 0.8	Fertile soil
High	0.9 – 1.5	Crops sensitive to salts are affected
Very high	> 1.5	Several crops are affected

the results of Mouhanni et al. (2011) and Gao et al. (2021), the provided average values of electrical conductivity did not show any significant difference between the two soil types.

Ammonium

Ammonium in the soil irrigated by the purified wastewater from the wastewater treatment plant in the town of Settat varies between a minimum of 1.8 mg/kg and a maximum of 15.33 mg/kg with an average of 9.62 ± 4.77 mg/kg, while the values obtained in the soils irrigated by rainwater vary between 2.39 mg/kg and 57.64 mg/kg with an average of 20.86 ± 19.44 mg/kg (Table 2). The results obtained show no significant difference after irrigation with the two types of water.

Nitrates

The concentrations of nitrates in the soils irrigated by treated wastewater vary between 10.64 mg/kg and 36.22 mg/kg with an average of 23.17 ± 8.34 mg/kg, while those obtained in the soils irrigated by rainwater vary between 1.18 mg/kg and 37.41 mg/kg with an average of 22.45 ± 11.25 mg/kg (Table 2). The nitrate averages of the two soil types are higher than those of ammonium, and this increase is explained by the transformation of ammonium into nitrates. The average nitrate values given do not show a significant difference between the two types of soil.

Phosphorus

According to El Oumlouki et al. (2014), phosphorus plays a very important role in the photosynthesis of plants and in the establishment of their root system. It is one of the major building blocks for plant growth. The results of the samples of the studied soils show that the phosphorus contents of the soils irrigated by the purified wastewater vary between 30.59 mg/kg and 180.53 mg/kg with an average of 64.14 ± 43.53 mg/kg. For the soils irrigated by rainwater, the phosphorus content varies between 3.58 mg/kg and 147.98 mg/kg with an average of 72.72 ± 58.59 mg/kg (Table 2). It was noted that the average phosphorus of the soils irrigated by rainwater slightly exceeds that of the soils irrigated by treated wastewater from the WWTP in the city of Settat, but the two types of soil are characterized by a high concentration of assimilable phosphorus

Table 5. Classes of assimilable phosphorus (P_2O_5) according to the standards of Delaunois et al. (2008)

Soil class	P_2O_5 (mg/kg)
Very weak	< 15
Weak	15 – 30
Well provided	30 – 45
High	45 – 100
Very high	> 100

(P_2O_5) according to the standards of Delaunois et al. (2008) (Table 5). The average phosphorus values given do not show a significant difference between the two soil types.

Potassium, sodium and calcium

The potassium values obtained in the soils irrigated by purified wastewater vary between 700 mg/kg and 1760 mg/kg with an average of 963 ± 321.49 mg/kg. The potassium contents in the soils irrigated by rainwater range between 300 mg/kg and 3620 mg/kg with an average of 1377 ± 1170.35 mg/kg (Table 2). According to these results and the standards of Delaunois et al. (2008) (Table 6), it was noticed that the two types of soil studied are characterized by a very high concentration that exceeds 300 mg/kg, especially the soils irrigated by rainwater, which indicates that these soils are very rich in potassium. Excess of the latter (K^+) in soils can have a negative impact through percolation and infiltration of salt, which is the result of the potassium transformation. This excess can also cause magnesium deficiencies in crops (Koné et al., 2009). No significant difference was recorded for soil potassium.

The sodium concentrations in the soils irrigated by treated wastewater vary between a minimum of 760 mg/kg and a maximum of 1100 mg/kg with an average of 947 ± 112.25 mg/kg, while those found in the soils irrigated by stormwater oscillates between 190 mg/kg and 1500 mg/kg with an average of 586 ± 403.38 mg/kg (Table 2). The results obtained show a significant difference ($P_{\text{value}} < 0.05$) (Table 2) by recording high sodium concentrations in the soils irrigated by purified wastewater, something which was also confirmed by Tarchouna et al. in 2010 and Njimat et al. in 2021. This is perhaps due to the accumulation of sodium caused by the irrigation of the soil by the purified wastewater of the STEP of Settat. Excess sodium in soils can deteriorate their structure by reducing compaction and water circulation.

The calcium content in the soils irrigated by treated wastewater varies between 6540 mg/kg and 7880 mg/kg with an average of 7003 ± 538.29 mg/kg. For the soils irrigated by rainwater, the content of this element ranges between 6900 mg/kg and 9460 mg/kg with an average of 8471 ± 887.44 mg/kg. A statistically significant increase in the calcium content was found in the soils irrigated by rainwater, unlike the purified wastewater from the Settat WWTP which contains less calcium (Table 2).

Rainwater irrigation promoted calcium accumulation in the soils. In contrast, the potassium (K^+) concentrations were lower in the soils irrigated with treated wastewater, indicating that high concentrations of calcium (Ca^{2+}) in treated wastewater likely improved the K^+ uptake by treated wastewater peach trees or favored leaching of K^+ by contributing to adsorption on soil surfaces (Tarchouna et al., 2010).

Organic matter

Soil organic matter is an important indicator of soil quality degradation due to its contribution to soil stability and increased soil water retention capacity, as well as fixation of mineral elements and the substrate for soil microorganisms (El Oumlouki et al., 2014). The organic matter content of soils can be influenced by several factors, such as climate, soil texture, vegetation and topographic conditions (Drouet, 2010). The results of the studied soils show that

Table 6. Classes of exchangeable potassium (K_2O) according to the standards of Delaunois et al. (2008)

Soil class	K_2O (mg/kg)
Very weak	< 60
Weak	60 – 100
Well provided	100 – 180
High	180 – 300
Very high	> 300

Table 7. Classes of organic matter according to DIAEA/ DRHA/SEEN (2008) standards

Soil class	Organic matter (%)
Very poor	< 0.7
Poor	0.7 – 1.5
Moderately poor	1.5 – 3
Rich	3 – 6
Very rich	> 6

the percentage of organic matter in the soils irrigated by purified wastewater varies between 3.02% and 5.21% with an average of $3.78 \pm 0.59\%$, while the percentage of matter organic in the soils irrigated by rainwater oscillates between 2.57% and 5.67% with an average of $3.69 \pm 0.89\%$ (Table 2). The averages of the two soil types are very close to each other, and the results obtained show that these soils are rich in organic matter according to the DIAE/DRHA/SEEN (2008) standards (Table 7). No significant difference was recorded for this parameter.

Cation exchange capacity

According to McGahuey (2021), cation exchange capacity (CEC) is the ability of a soil to retain essential nutrients. It is based on the principle of saturating a soil with sodium (Na), which theoretically replaces all cations present in the exchangeable portion of the soil. The sodium is then leached by an ammonium solution and determined. The amount of sodium thus determined represents the cation exchange capacity of the soil in question (El Gharous et al., 1995). The cation exchange capacity of the soils irrigated with treated wastewater varies between 29.02 meq/100g and 87.28 meq/100g with a mean of 50.71 ± 21.84 meq/100g, and that of the soils irrigated with rainwater varies between 26.85 meq/100g and 55 meq/100g with a mean of 39.13 ± 8.67 meq/100g (Table 2). The cation exchange capacity values of the two soil types were lower than the sum of the means of potassium (K^+), sodium (Na^+) and calcium (Ca^{2+}) especially for the rainfed soils, indicating that some of the exchangeable cations were not on the exchange complex but stored as labile salts or in a concentrated soil solution (Tarchouna et al., 2010). The average values given for cation exchange capacity do not show a significant difference between the two soil types.

Total nitrogen

The total nitrogen content in the soils irrigated by treated wastewater varies between 0.16% and 0.28% with an average of $0.2 \pm 0.03\%$, and that of the soils irrigated by rainwater varies between 0.14% and 0.32% with a mean of $0.21 \pm 0.52\%$ (Table 2). The average values given for total nitrogen do not show a significant difference between the two types of soil.

Total and active limestone

The contents of total limestone in the soils irrigated by the purified wastewater of the STEP of the city of Settat vary between 11.61% and 27.9% with an average of $15.65 \pm 4.96\%$, while those of the soils irrigated by rainwater range between 1.79% and 16.07% with an average of $5.85 \pm 4.47\%$ (Table 2). For active limestone, the contents obtained in the soils irrigated by purified wastewater vary between a minimum of 7.38% and 10.94% with an average of $8.71 \pm 1.14\%$, and those obtained in the soils irrigated by rainwater oscillates between 1.88% and 7.56% with an average of $4.4 \pm 1.86\%$ (Table 2). A statistically significant increase in the limestone content was recorded and it was high in the soils irrigated by the purified wastewater from the Settat WWTP. Irrigation with treated wastewater has favored the accumulation of limestone in the soil which can have an impact on the growth of calciferous crops.

CONCLUSIONS

The comparative study between the soils irrigated by treated wastewater from the wastewater treatment plant in the city of Settat and the soils irrigated by rainwater showed that irrigation by treated wastewater has positive effects on the contents of soil nutrients as well as a slight increase in soil salinization due to the electrical conductivity of the treated wastewater. Unlike the monitoring of the parameters studied which do not show any significant difference after irrigation with the two types of water, the obtained results reveal a significant difference in the contents of pH, sodium, total limestone and active limestone which present high levels in the soils irrigated by purified wastewater, and calcium which has high levels in the soils irrigated by rainwater.

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