Effect of irrigation with treated wastewater on geochemical properties (saltiness, C, N and heavy metals) of isohumic soils (Zaouit Sousse perimeter, Oriental Tunisia)

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Abstract

The use of treated wastewater in irrigation is increasing in Tunisia. However, it is imperative to study the impact of this water category on soil. Since 1995, the Zaouit Sousse perimeter (Tunisia) has been irrigated by treated wastewater. So, this sector is an excellent case study to evaluate the impact of the use of treated wastewater in irrigation on geochemical properties of isohumic soils.

Treated wastewater is characterized by high salinity. The Cd, Cr, Fe, Zn, Pb, Cu, Ni and Al concentrations of treated water range from 10 to 2510 µg L$^{-1}$.

In Zaouit Sousse, we examine seven irrigated sub-perimeters and seven profiles which differ by soil composition, texture and structure and irrigation periods (from zero to 14 years).

The present results showed that soil salinization is caused by high wastewater salinity and increases in irrigation period. The heavy metal content increases with irrigation period, especially for Pb (1010–1890 µg kg$^{-1}$) and Cd (2–20 µg kg$^{-1}$). The pH values of the water and soil are slightly basic. The metals’ migration will especially depend on the concentration of organic carbon and of the soil nature.

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1. Introduction

Within countries of the southern part of the Mediterranean Sea, natural water resources are limited, whereas their demand is constantly increasing. Therefore, non-conventional water resources became important to satisfy different agricultural needs. In Tunisia, the reuse of treated wastewater (TWW) has been adopted since the 1960s with the planning of many irrigated perimeters.

The primary and secondary wastewater treatments improve distinctly the water quality although the treated wastewater still retains a substantial amount of organic and metallic compounds (e.g. C, N, P and K which had a favourable effect on the growth of certain crops [3,4]). It can cause soil quality modification by structure deterioration (salinization splash of clays,...) and soil pollution (mineral, organic, bacteriological pollution, etc) [3,4]. Therefore, the reuse of this wastewater category will have some serious consequences on natural resources [5–8]. The total pollutant content of water used for irrigation is not the only parameter of which depends the soil pollution. Indeed, the total pollutants content in soil depends on the physicochemical parameters and the mechanisms that govern their distribution and their transport [9]. So, the nature and the soil composition, the climate and the crops’ nature play an important role in fixing and the infiltration (toward the different horizons of our soil) of contaminants and their transfer toward plants and groundwater [5–8,10–13]. The long use will also serve as a parameter of soil pollution.

The Zaouit Sousse sector is an excellent case where you can evaluate the effect of the use of treated wastewater on geochemical properties of sandy to sandy-clay soils as pH, carbon, C/N ratio and major elements. We also aimed to identify the heavy metal content in surface and deeper soil sediments (until 120 cm) and the possible factors (organic matter, sand and clay fractions) which can affect heavy metals’ mobility in sandy to sandy-clay soils covered by olive trees, bersim and the sorghum.

2. Materials and methods

2.1. Geographical localization

The perimeter of Zaouit Sousse is a part of the Tunisian central Sahel. It is situated in the South of Sousse city (Longitude: 35° 47’, Latitude: 10°38’ and of altitude: 20 m N.G.T.) (Fig. 1).
The perimeter covers 450 ha, 205 ha of which are currently exploited. Sousse Sebkha and Oued Hamdoun assure the drainage of the perimeter which developed on alluviums of tertiary and quaternary age \[14,15\]. Soils present an isohumic characters and are covered by olive trees underneath there is bersim (in winter) and the sorghum (in summer).

Since 1989 to 2003 (the year of our field sampling), the perimeter is irrigated by wastewater from the Sousse treatment plant. The irrigation periods vary from a sub-perimeter to another one. The Zaouit Sousse sector is composed, indeed, of many sub-perimeters. Only 7 sub-perimeters are chosen. It defers by the irrigation period which varies between zero and 14 years and/or by the mineralogical composition, the texture and the structure of the soil. In every sub-perimeter, we chose a profile type (Fig. 2).

2.2. Methodology and analytical techniques

2.2.1. Methodology

To reach our goal, we focus on granulometry, dosage of the limestone (total and active), organic carbon, nitrogen, electric conductivity, pH, major elements (Na, Ca, Mg, and K) and trace heavy metal (Zn, Cr, Cu, Pb, Fe, Ni and Al). Since the periods of irrigation are known and different from a sub-perimeter to another one, it permits us to study the effect of the irrigation period on soil properties (salinization, metallic pollution). To study the vertical propagation of pollutants, the different horizons of every profile have been sampled.

For a correct assessment of the degree of soil contamination, it is necessary to have a background in heavy metals, electric conductivity and organic carbon contents in order to make a right comparison. A comparable zone to our studied area and without any pollution source has been chosen.

Before studying soil, it is imperative to have an idea on the global composition of this TWW used for irrigation.

2.2.2. Analytical techniques

2.2.2.1. Soils. For every profile a fine morphological survey and its textural class has been determined, according to the GEPPA method \[16\].

Within every profile and for every horizon, about 1 kg of cool soil sample has been appropriated, homogenized and conditioned then in the plastic bags.

The samples have been dried at 40 °C thereafter and have been sifted to 2 mm. Granulometric analysis has been achieved according to the method to the Andersen pipettes \[17\]. The pH and the electric conductivity (EC) has been respectively measured with pH-meter LPH 230 T-type and conductimeter ORION 150-type with platinum electrode, in a soil–water suspension (10 mg of soil in 50 ml of water distilled) after 2 h of agitation \[18\]. The dosage of the total and active limestone is achieved according to the French norms \[17\]. The electric conductivity (EC) has been measured on the same suspension with a conductimeter model ORION 150. The organic carbon (OC) and the organic nitrogen (ON) have been analyzed respectively by the ANNE and the Kjeldhal methods. The organic matter yield of soil (OM) is appraised while multiplying the percentage of the organic carbon by the factor 1.724 \[19\].

For the major (Na, K, Mg, Ca) and traces elements (Cd, Cr, Fe, Pb, Zn, Al, Cu, Ni) analyses, 0.5 g of soil have been attacked by a mixture of...
5 ml of HF, 1.5 ml of HClO₄, 3.75 ml of HCl and 1.25 ml of HNO₃ [19]. The respectively yields of the last for acids are 40%, 70%, 37% and 65%. The reaction is done in bath sand at 250 °C. When the reaction is finished, the product is dissolved in 100 ml of ultra pure water. The solution is analysed and we deduce the concentration of 1 kg of sediment. 20% of samples and the samples which show the extreme concentrations are duplicated. The reference samples are those of CRPG standards (Nancy—France).

Analyses are done with Atomic Absorption Spectro-photometry (AAS) VARIO6 type with graphite furnace where the detection limit

![Fig. 2. The logs of the seven studied profiles.](image-url)
concentrations are respectively 87.9 (TS: 90 mg L\(^{-1}\)) and 18.5 mg L\(^{-1}\) (TS: 10 mg L\(^{-1}\)). The mean Cl content is 688 mg L\(^{-1}\) (Tunisian Standards (TS: 7 mmhos cm\(^{-1}\)). The BOD\(_5\)/COD ratio is equal to 0.22. This much lower value (7.71) indicates a bad water quality (referring to major ions) and a high risk of salinization.

The Cd, Cr, Fe, Zn, Pb, Al, Cu and Ni concentrations of treated wastewater of South Sousse plant, and for the same period, range from 20 to 2500 µg L\(^{-1}\) (Table 1). These values are relatively high, by comparison to the mean values presented by Bahri (1995) [4]. Probably, the increase of heavy metals' concentration of the treated wastewater of South Sousse plant is only due to the increase in industrial wastewater quantity which is rich in heavy metals. But these values remain relatively low with respect to the Tunisian Standards, except the Cd (30 µg L\(^{-1}\)) and Pb (2510 µg L\(^{-1}\)) which exceed the Tunisian guideline values and present therefore a potential pollution risk (Table 1).

### 3.2. Granulometric data

The granulometric analyses results show that the percentages of different fraction distribution for every horizon and for every profile are very variable. For the seven profiles, the clayey fraction varies between 9.5 and 33.25%; the Loamy fraction is between 0.5 and 45.50%; the sand fractions vary between 30.85 and 96.91% (Table 2).

The plotting of these results on the textures triangle of the U.S.D.A. [22] shows that the soils, generally, present uniform and balanced textures. They are classified as sandy and sandy-clay.

These soils have a homogeneous composition and the sandy nature of samples will allow the infiltration of pollutants. Nevertheless, due to the relatively high percentage of clay fraction the possibility of pollutants adsorption is relatively high.

### 3.3. pH, Carbon and N analyses

The pH values vary between 6.9 and 8.4. The highest values are localized in depth (Table 2). The organic carbon contents (%C) range from 0.25% to 0.98%. The CaCO\(_3\) values range from 5.56% to 47.86%.

The Nitrogen (N) values range from 0.027% to 0.097%. The carbon decrease while those of limestone increase (Table 2). The increase in the CaCO\(_3\) content is due to the increase in the chalky crust which was presented as a soft nodular in the deeper horizon.

In all profiles, the presence of the organic matter and chalky crust in depth characterizes the carbonate and isohumic soils in the Tunisian Sahel [23].

### 3.4. Water quality

To give a precise idea about the TWW quality used for Zaouit Sousse irrigated perimeter, we made a statistical survey of physicochemical parameters analyzed by the National Agency for Wastewater Management [20,21] for 2 years. According to the results and statistical study the treated wastewater composition is slightly the same during the analysed period. The results revealed that the mean EC value is 3.5 mmhos cm\(^{-1}\) (Tunisian Standards (TS: 7 mmhos cm\(^{-1}\)) and slightly alkaline (mean pH value = 7.8). The mean Cl content is 688 mg L\(^{-1}\) and is lower than the Tunisian Standards (2000 mg L\(^{-1}\)). The MS (Material in Suspension) content is of 32.7 mg L\(^{-1}\) (TS: 30 mg L\(^{-1}\)). The COD and the BOD concentrations are respectively 87.9 (TS: 90 mg L\(^{-1}\)) and 18.5 mg L\(^{-1}\) (TS: 30 mg L\(^{-1}\)). The BOD\(_5\)/COD ratio is equal to 0.22. This much lower ratio is only due to the increase of industrial wastewater origin (more than 70%) where you have a low biodegradable compounds and a slow accumulation of the reference bacteria to unusual molecules such as molecules colouring which are very frequent because this zone is known by the textile industry (ONAS, oral communication (2007)).

We notice that to eliminate the human community risking, the farmer must use special equipments during their work time.

The concentrations of Na, Ca, Mg, and some K show that this water is strongly mineralized, with the average contents of Na = 112 mg L\(^{-1}\), Ca = 258 mg L\(^{-1}\), Mg = 166 mg L\(^{-1}\) and of K = 333 mg L\(^{-1}\). The estimated SAR value (7.71) indicates a bad water quality (referring to major ions) and a high risk of salinization.

The Cd, Cr, Fe, Zn, Pb, Al, Cu and Ni concentrations of treated wastewater of South Sousse plant is only due to the increase in industrial wastewater quantity which is rich in heavy metals. But these values remain relatively low with respect to the Tunisian Standards, except the Cd (30 µg L\(^{-1}\)) and Pb (2510 µg L\(^{-1}\)) which exceed the Tunisian guideline values and present therefore a potential pollution risk (Table 1).

### Table 1

<table>
<thead>
<tr>
<th>Elements</th>
<th>T.W.W.</th>
<th>T.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd µg L(^{-1})</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Cr µg L(^{-1})</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Fe µg L(^{-1})</td>
<td>1300</td>
<td>5000</td>
</tr>
<tr>
<td>Zn µg L(^{-1})</td>
<td>180</td>
<td>500</td>
</tr>
<tr>
<td>Pb µg L(^{-1})</td>
<td>2510</td>
<td>1000</td>
</tr>
<tr>
<td>Al µg L(^{-1})</td>
<td>2250</td>
<td>5000</td>
</tr>
<tr>
<td>Cu µg L(^{-1})</td>
<td>90</td>
<td>500</td>
</tr>
<tr>
<td>Ni µg L(^{-1})</td>
<td>80</td>
<td>200</td>
</tr>
</tbody>
</table>

The C/N ratios in the different horizons of the studied profiles vary and range from 9.02 to 13.87 (Table 2). The elevated values in some profiles are probably owed to the soils' amendment by organic remnants of olive trees. It is known that these rich remnants which composed by lingo-celluloses have nitrogen weak contents and thereafter elevated C/N yield [24].

3.4. Salinity (electric conductivity)

For the seven studied profiles and for all the horizons, the EC is higher than those of the Pf1 (Control sub perimenter — Table 3) and background profiles (Table 4). First, we notice that the EC variation is not reflecting the differences of analysed major element contents (Table 3). This difference is probably due to other not determinate elements like chlorides. We remark too that:

- the soil samples of the profile 4 have the highest EC (between 4.54 and 6.96 mmhos cm⁻¹). The increase of the salinity is probably the result of lagoon water infiltration due the location of this profile near the border of the sebkha. We notice that the recent measures show that the soils which are in the vicinity of the lagoon are highly salted. Their EC values are equivalent of those of Pf6.
- for the profiles 2, 3, 5, 6 and 7, the electric conductivity of soil samples is equal or lower than 3.0 mmhos cm⁻¹. More precisely and except the Pf7 which irrigated along 14 years, the soil EC is equal or lower than 1.46 mmhos cm⁻¹ (Table 3).

These profiles show, also, the existence of two salinity tendencies:

- increasing of salinity from the top to bottom for Pf2, Pf3, Pf5, Pf6 and Pf7 profiles with an important salt concentration at the deep horizons (Fig. 3 and Table 3). We remark that these variations are not important in some profiles,
- a spatiotemporal distribution (except Pf5): the salinity of surface soil-sediments increases with the irrigation period (Fig. 4). The sub-perimeter Pf7 knows a rather particular situation. It is totally abandoned (since 2002) and the soil is crowed together and the water infiltration became very slow. We add, because the water of irrigation arrived to various sub-perimeters in a craft way, regularly there is water flow towards the Pf7 which is in a topographic depression. So, there is often a stagnant wastewater. In Zaatou Sousse, the rainfall is about 450 mm/year and the evapo-transpiration (ET) mean value is 1230 mm/year [25]. Therefore, the stagnation of non-negligible rich salt water and it evaporation has largely contributed to the soil salinity increase. These facts are responsible for the abnormal EC values.

![Fig. 3. Salinity variation according to the soil depth in profiles 1, 2, 3, 5, 6 and 7.](image-url)
Sousse irrigated perimeter, you can't suggest any clear conclusion

Significant to groundwater and contribute to groundwater salinity increase.

Because the soil EC is widely lower than used treated wastewater. Since these salts are highly soluble, they infiltrate and accumulate in the deeper horizons which explain the first observed gradient. Because the soil EC is widely lower than used treated wastewaters (3.5 mmhos cm\(^{-1}\)) only a little part of the residual dissolved solid is accumulated and the main salt quantities is leached from sediments and normally accumulate in the groundwater. To verify this hypothesis, we will have to draw up a qualitative and quantitative balance sheet of the groundwater\[26]. Zaouit Sousse is an irrigated perimeter which is in the border of Sousse sabkha. The overexploitation of this aquifer, led to the decline of the piezometric levels and afterward was lagoon water intrusion and consequently to an increase of the groundwater salinity which reached about 16 gL\(^{-1}\). The balance sheet of dissolved salts in this aquifer does not allow us to clarify salt part leached from the soil. However, the salt solubility, in the physicochemical conditions of the irrigated soil (isohumic), is clearly more significant than of Cd and Cr. Consequently, the salts and especially the chlorides of treated wastewater infiltrate more quickly than the metals towards ground water\[27]. So, we suggest that significant quantity of salt infiltrate with the Cd and Cr to groundwater and contribute to groundwater salinity increase.

The pH versus the application time of the TWW doesn't show a significant variation (Fig. 4). If we limited to the results of the Zaouit Sousse irrigated perimeter, you can't suggest any clear conclusion because the soil pH of the background and Pf\(_1\) profiles are 8.0 and those of the irrigation water are on average 7.8. But we remark that the increasing tendency of pH seen at Zaouit Sousse is noticed in the Tunisian isohumic soils. Since this work is still in progress.

3.5. Major elements concentration (Na, Ca, Mg and K)

The major element contents of the Na, Mg and K which determine presumably the soil salinity ranged from 108.6 to 359.8 meq kg\(^{-1}\). (Table 3). These results show that the treated wastewater has charged enough in salts the soil. In our case, it is difficult to show the impact of the Ca and Mg on the soil salinity since the total limestone is very abundant (Table 2). For the Na and the K, the correlation diagrams EC–Na and EC–Na + K of the surface soil-sediments, show a positive correlation. This good correlation indicates that the salinity of soil in Zaouit Sousse depends, among other things, of Na and K contents. We note that in the correlation diagrams we are not taken into account Pf\(_2\) and Pf\(_4\) because the relative high salinities of Pf\(_2\) is probably due to the stagnation of water while for Pf\(_4\) it is probably the result of the lateral brines infiltration because this sub-perimeter is on the verge of the sebkha.

Because the presence of the Na, the use of this water type will be able to tamper the soil structure and might lead to its deterioration (Table 3).

For the moment, we do not note problems in Zaouit Sousse soil since the chemical composition of the ground is balanced. Indeed, the Na abundance in the water irrigation of South Sousse plant can be at the origin of the clays deflocculating and proofing of the soils\[28–32]. However, the treated wastewater is rich in Na, the presence of Ca and Mg in carbonate soil (Table 2 and 3) maintained the structural soil stability and attenuated the effect of deflocculating of clay by the Na ions\[32,33]\.

We note limestone yield and organic carbon content in the irrigated sub-perimeters have the same tendency of evolution.

3.6. Heavy metal content

3.6.1. Background concentration of heavy metals

The knowledge of background concentrations of heavy metals in soil is one of most important issue for correct assessment of the degree of soil contamination. In the literature, different definitions are proposed\[34–37]\.

But in general, it is impossible to have only one level background\[36]\. Consequently, different heavy metals background

<p>| Table 5: Heavy metals contents (Cd, Cr, Fe, Zn, Pb, Al, Cu and Ni) of soils (μg kg(^{-1})). |
|----------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|</p>
<table>
<thead>
<tr>
<th>Profile</th>
<th>Depth</th>
<th>Cd</th>
<th>Cr</th>
<th>Fe</th>
<th>Pb</th>
<th>Zn</th>
<th>Al</th>
<th>Cu</th>
<th>Ni</th>
<th>OM</th>
<th>OM + Clay</th>
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<tbody>
<tr>
<td>Pf(_1)</td>
<td>0–35</td>
<td>3</td>
<td>172</td>
<td>419</td>
<td>98</td>
<td>98</td>
<td>1561</td>
<td>5</td>
<td>145</td>
<td>0.64</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>35–120</td>
<td>1</td>
<td>189</td>
<td>474</td>
<td>901</td>
<td>96</td>
<td>1925</td>
<td>4</td>
<td>144</td>
<td>0.95</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>50–120</td>
<td>7</td>
<td>270</td>
<td>1062</td>
<td>782</td>
<td>260</td>
<td>2721</td>
<td>47</td>
<td>163</td>
<td>1.69</td>
<td>23.19</td>
</tr>
<tr>
<td></td>
<td>0–20</td>
<td>2</td>
<td>211</td>
<td>784</td>
<td>1007</td>
<td>276</td>
<td>2161</td>
<td>32</td>
<td>241</td>
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<tr>
<td></td>
<td>12</td>
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<td>1367</td>
<td>987</td>
<td>340</td>
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<td>204</td>
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<tr>
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<td>20–48</td>
<td>3</td>
<td>395</td>
<td>1694</td>
<td>1038</td>
<td>369</td>
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<td>87</td>
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<td></td>
<td>48–120</td>
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<td>1162</td>
<td>1061</td>
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<td>3153</td>
<td>45</td>
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<tr>
<td>Pf(_2)</td>
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<td>3</td>
<td>262</td>
<td>763</td>
<td>2061</td>
<td>171</td>
<td>2936</td>
<td>65</td>
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<td></td>
<td>40–120</td>
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<td>186</td>
<td>540</td>
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<td>84</td>
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<tr>
<td></td>
<td>0–20</td>
<td>14</td>
<td>147</td>
<td>248</td>
<td>1074</td>
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<td>75</td>
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<td>1.16</td>
<td>10.66</td>
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<td>20–90</td>
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<tr>
<td></td>
<td>90–120</td>
<td>23</td>
<td>206</td>
<td>2087</td>
<td>1234</td>
<td>69</td>
<td>5323</td>
<td>18</td>
<td>144</td>
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<td>18.79</td>
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<tr>
<td>Pf(_3)</td>
<td>0–60</td>
<td>26</td>
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<td>552</td>
<td>1219</td>
<td>111</td>
<td>2530</td>
<td>41</td>
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<td>29</td>
<td>251</td>
<td>698</td>
<td>1893</td>
<td>160</td>
<td>2830</td>
<td>63</td>
<td>180</td>
<td>1.28</td>
<td>31.28</td>
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<tr>
<td></td>
<td>0–30</td>
<td>12</td>
<td>403</td>
<td>1418</td>
<td>1315</td>
<td>406</td>
<td>3696</td>
<td>92</td>
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<td>1.69</td>
<td>30.94</td>
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<td>537</td>
<td>1526</td>
<td>97</td>
<td>2207</td>
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<td>12</td>
<td>263</td>
<td>774</td>
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<td>2918</td>
<td>58</td>
<td>170</td>
<td>0.64</td>
<td>26.14</td>
</tr>
</tbody>
</table>

\(\text{Pf}\) European Community\(^a\) 1–3 100–150 \(\sim\) 50–300 150–300 \(\sim\) 50–140 30–75

\(\text{United States}\)\(^b\) 20 1000 \(\sim\) 1400 \(\sim\) 750 210

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\(^b\) United States, Directives NRC, 2002.
3.6.3. Heavy metals and soil constituent (organic matter and clay)

According to several studies [40,42,43], the migration of heavy metals in irrigated soil is observed at different depths, respectively to 10 cm, 20 cm, 50 cm or 80 cm.

Their accumulation can decrease with depth [44]. However other studies [43,45], showed that the heavy metals contents could be lower after 4 irrigation years by polluted water.

These variations are a consequence of the heavy metals mobility, adsorption, precipitation and leaching depends on the variability of structural, textural, composition of soils and the physicochemical processes [8,10,24,46–51]. For example, the pH, the presence of nitrogen and organic matter can have a strong influence on metal mobility. In Zaouit Sousse, since the pH of the water used for irrigation and soil are slightly basic, the metals migration will essentially depend on the organic matter concentration and the soil nature.

For the Pf6, we have a Cr, Zn, Cd, Fe, Cu and Pb in deep horizons due to the increase of organic matter in depth. On the other hand, in Pf5, Pf4 and Pf3, the OM content is abundant in the superficial soil layer and complexing essentially the Cu, Cr, Al, Cd and Fe. These results show that the metals contents in the different horizons are related to the increase of the percentage of the OM content (Table 5). The organic matter of our soil is probably associated to the solid phases. Janos et al. [12] indicated that the organic matter associated to the solid phases play an important role on metal immobilization (it is our case). Further, the soluble organic components are going to favour the metals mobility and to increase their total concentration in solution [52].

We also note that Cr, Zn, Cd, Fe, Cu and Pb have tendency to accumulate in surface horizons when the fraction of soil sediments is fine (Pf3, Pf4, Pf5 and Pf6) (Table 2 and 5). But for the profiles 5 and 6 where the granulometry of the sandy soil is bigger, the permeability is higher and the infiltration is fast, the heavy metals accumulated in depth.

The correlation diagram organic compounds +% clay versus total of metal contents ($r^2 = 0.75$) confirm our observation.

Consequently, we can suggest that the quantity of heavy metals trapped within the different horizons increases when the quantity of the organic matter associated to the solid phases and the percentage of fine sand and clay fraction increase.

3.6.4. Metal load evolution according to the time

We are tempted to see if the irrigation period plays a determining role in the metallic soil contamination (as for the salinity). The diagram of metal concentrations distribution measured out of surface horizons according to the time of treated wastewater applications (for four profiles) show that the quantity of Cr, Zn, Cu and Ni accumulated at the surface horizons is proportional with the irrigation time (Table 5 and Fig. 5).

These results are in agreement with those of other authors [3,5] who show that the irrigation by the treated wastewater carry away an important increase of heavy metals contents in soil surface horizons.

4. Conclusion

The BOD and COD concentrations and also the CE and pH values measured in treated wastewater are lower than Tunisian Standards but this water is relatively abnormally rich in Na, Ca, Mg, and K. In spite the Ca and Mg important content, the SAR stays high.

The pH, organic compounds (C and N), salinity, some major elements (Na, Ca, Mg, K) and the soil EC indicates that the extended irrigation with treated wastewater involves, in our case, the increase of its salinity, which is dependent of the irrigation period. This salinization by Na could be responsible for the change the soil structure.

However due to the high Ca and Mg concentrations of the treated wastewater and also the presence of carbonate phases on the soil, is responsible for the Zaouit Sousse soil kept the same structures.

The heavy metals concentrations in soil indicates that their mobility and their adsorption will depend on the metallic contents.
of treated wastewater, the organic carbon tenors, the percentage of the clay fraction and the irrigation time. The irrigation with treated wastewater could increase the salinity and the heavy metals contents of the soil. But thanks to the nature of the soil, its structure and the mobility of metals stay without danger. So, we can continue the irrigation with treated wastewater but we always have to follow the evolution to be able to foresee, in time, the possible exploitation problems.

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