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30 years saline water irrigation effects on soil characteristics

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***Abstract*— The use of saline waters in irrigation may result in adverse effects which may appear in the long terms on the water-soil system. In this context, this study was conducted in the Public Irrigation Zone Zelba 1 (Eastern Tunisia) irrigated for 30 years using brackich water. The study mainly focused on soil texture, pH, electrical conductivity, sodium adsorption ratio and exchangeable sodium percentage. Soil physical characterization showed that soils in the irrigation zone are isohumic, with sandy-silt to clay-silt texture. Soil chemical characterization showed that soils are alkaline, with an average pH of about 8.7. The values of the saturated-paste electrical conductivity increased with depth from 5.3 (±0.35) to 11.9 (±0.15) dS/m for the irrigated soil and from 6.9 (±0.49) to 12.2 (±0.9) dS/m for the non-irrigated soil. This increase could be due to the salt leaching after irrigation and rainwater infiltration. Sodium adsorption ratio and exchangeable sodium percentage values observed along the soil profile are greater than 10 and 15% respectively. The use of brackish water was shown to have a significant effect on the evolution of the sodium content in the soil. Therefore, this use could increase the risk of soil salinization and sodisation in the long terms.**

***Index Terms*— Saline water, Soil characterization, Salinity, Sodicity.**

I. INTRODUCTION

Water is the vital element of any development plan. It is one of the most important resources for economic growth and human communities' development [1]. However, water shortage, its erratic distribution and its often poor quality, characterizing the southern Mediterranean region, are becoming a serious problem, which often affects economic, urban and agricultural activities [2]. Besides, high water consumption is recorded to meet the ever increasing demands of irrigation, industry and domestic use, especially because by the important demographic expansion [3]. Therefore, the use of water marginal quality is becoming an important consideration particularly in the irrigation sector [4].

Irrigation is a determinant factor of the agricultural intensification. Moreover, irrigation is the largest consumer of water resources and the least demanding in terms of quality. It allows the intensification of agriculture, the improvement of yields and the stimulation of production. Nevertheless, it may produce harmful environmental effects. Indeed, irrigation with poor-quality water like drainage water, treated wastewater, brackish or saline water induces in the short-term, degradation of agricultural soils including salt accumulation and, over time, the salinization of the aquifer. Soil salinization may result in reducing soil fertility, resulting in reduced crop yields [5].

Many works conducted in different regions of the world (Spain, China, Morocco, Algeria, Tunisia, etc.) have reported that saline water used for irrigation, without taking into consideration surroundings conditions, induced soil salinity increase [4]-[6]-[7]-[8]-[9]-[10]. In Tunisia, irrigation zones are characterized by a progressive soil salinization, especially located in the south of the country. According to [11], the most important cause of soil salinisation is the use of highly saline water for irrigation. This use is expanding, such as in irrigation zones of Mahdia [12], Sfax [13], Gabes [14], and Kebilli [15]. In the region of Mahdia (Eastern Tunisia), soils and aquifers salinization is a widespread and expanded phenomenon, mainly due to the extensive and irrational use of water resources in irrigation. These water resources come from deep aquifers presenting a high salinity (5<total dissolved solids (TDS) <6 g/l) [16].

Irrigation by poor quality water was practiced in the Public Irrigation Zone (PIZ) Zelba 1 of the region of Mahdia for 30 years. This irrigation zone was almost abandoned and its exploitation declined considerably in recent years because of the significant soil salinization, recorded especially in the last decade. In this case, this paper aims to diagnose the current state of the PIZ Zelba 1 in order to show the effects of soil salinization and sodisation in the long-term and to suggest adequate solutions for better soil and water management. Thus, water and soil characterization were interpreted and discussed, especially soil salinity, through the study of salt profiles variation between irrigated and non-irrigated soil.

II. MATERIALS AND METHODS

A. Study area

The PIZ Zelba 1 was created in 1986. This area is located in the center of an alluvial plain of the region of Zelba, situated in the south of Sidi- Alouane at about 35 km southwest of the town of Mahdia (Fig.1).

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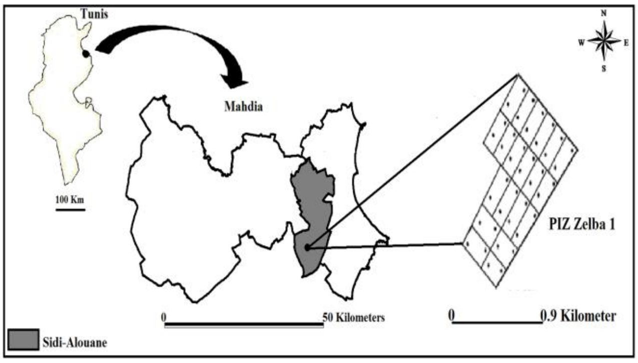

Fig. 1. Presentation of the Public Irrigation Zone Zelba 1 and sampling points' location

The region of Zelba is characterized by an arid climate. Precipitation is highly variable and irregular with an annual average of about 288 mm. Annual average temperatures is about 19.3°C. The PIZ Zelba 1 covers 60 hectares consisting of 20 lots of 3 ha each. Fig.2 shows a typical lot. Adopted crops are mainly: cotton, sorghum, barley, oats, corn, vegetables and fruits. Regarding cleansing, the irrigation zone is crossed by two drainage ditches leading to a pit latrine. Currently, no water flows through this network of ditches completely dry. Irrigation water comes from the Zelba 1 well capturing a deep aquifer (depth=400 m) debiting 18 l/s.

B. Irrigation water characterization

Water samples were taken directly from the deep aquifer according to the norm ISO 5667-11. They were kept at low temperatures (T<4°C) for the analysis of different parameters in the laboratory such as: potential of hydrogen (pH), electrical conductivity (EC), total dissolved solids (TDS), cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and anions (SO_4^{2-}, Cl^- and HCO_3^-). The pH was measured using a pH meter electrode immersed directly in the irrigation water. The EC was evaluated using a conductivity meter equipped with a temperature correction setup which allowed direct measure at the reference temperature of 25°C. The TDS was measured by drying a total volume of 50 ml of the aqueous extract in an oven at 110°C for 24 hours.

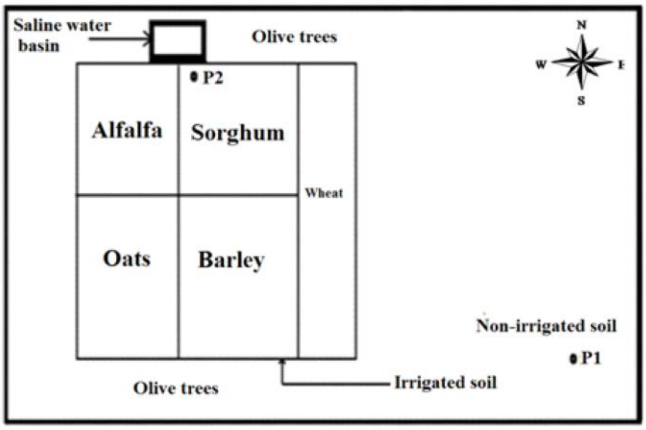

Fig. 2. Presentation of a typical lot of the irrigation zone and localization of the studied profiles

The ionic balance analysis was determined by volumetric proportioning based on the principle of Mohr for chlorides (Cl^-), carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), calcium (Ca^{2+}) and magnesium (Mg^{2+}). The proportioning of sodium (Na^+), potassium (K^+) and sulfate (SO_4^{2-}) was based on the principle of flame spectrophotometer. In fact, chlorides were determined using a standard solution of silver nitrate ($AgNO_3$, 0.02N) in the presence of potassium chromate ($KCrO_4$). Chlorides were precipitated in the form of silver chloride (AgCl). Bicarbonate proportioning was conducted by acidimetry using sulfuric acid (H_2SO_4, 0.02N). The colored indicator used is green bromocresol which gives a blue color. Calcium was proportioned by complexometry at pH=10 in the presence of (NaOH). Titration was carried out using tetraacetic ethylene diamine. Magnesium was calculated by the difference of the total hardness and the calcium. Sodium and potassium proportioning was based on the atoms dissociation during their passage through the flame which emit energy to their excitement. Then each element emits a specific wavelength detected by optical filters of each element. Sulfates were analyzed using stabilized Barium Chloride (Cl Ba).

The proportioning of cations: (Ca^{2+} Mg^{2+} and Na^+), provides the sodium adsorption ratio (SAR) according to the Equation (1). Indeed, the determination of SAR allows assessing the eventual degradation of the soil structure and the alteration of its properties.

$$\mathrm{SAR} = \frac{\mathrm{Na}^+}{\sqrt{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})/2}} \qquad (1)$$

Where concentrations of Na, Ca and Mg are expressed in meq/l.

C. Soil characterization

Soil sampling was carried out, at many depths (up to 1.5 m), in 20 lots of the irrigation zone in order to characterize the studied soils and their salinity state. Indeed, two soil profiles per plot (irrigated and non-irrigated) were collected in a systematic manner with an auger in order to have a soil sample for each 15 cm (Fig. 2). Thus, about 500 g from each level was taken in a plastic bag, identified by the number of the plot and the profile depth. The collected samples have served for the reconstitution of soil profiles in the laboratory in order to identify and to characterize different constitutive layers of soil (color, presence or absence of calcareous nodules, presence or absence of plant debris, etc.). Then, a composite sample was taken from each identified layer of the reconstructed profile for analysis in the laboratory. Soil samples were air-dried, crushed and sieved at 2 mm. The fraction less than 2 mm was used for the analysis of physical, chemical and mineralogical properties.

Physical analyses were realized in the High Institute of Agronomy of Chott Mariem. Examined physical properties are: soil texture, soil permeability (K) and bulk density (BD). Soil texture was carried out on a representative sample for each layer of the irrigation zone using the Robinson pipet's method. This method consists in separating the mineral portion of the soil in fractions classified according to the size of particles less than 2 mm. Soil permeability was determined by the double cylinder method based on the principle of vertical infiltration. Bulk density was determined based on a representative soil profile dug in the center of the irrigation zone, using the metal cylinder method open in two extremities with a given volume. In fact, this cylinder was pressed at various soil depths. The obtained soil samples were dried in an oven at 105°C for 24 hours in order to determine the dry mass [17].

Chemical analyses realized in the laboratory are, total calcareous (TC), active calcareous (AC), organic matter (OM), total nitrogen (N), cation exchange capacity (CEC), potential of hydrogen (pH), electrical conductivity (EC), ionic balance of the soil solution, exchangeable cations and exchangeable sodium percentage (ESP).

The TC proportioning was done by the volumetric method using the calcimeter of Bernard and the AC was determined by Drouineau-Roller's method. The Walkey-Black's method, based on the soil carbon oxidation principle using a potassium dichromate, was used to determine the organic matter content. Total nitrogen was determined using the Kjeldahl's method by attacking at high temperatures the living matter using concentrated sulfuric acid in the presence of a catalyzer. Cation exchange capacity was determined based on a representative sample for each layer of the irrigation zone using the Ulrich Riehm method. Soil pH was measured in a soil/distilled water ratio of 1/2.5 by the electrometric method using a pH meter equipped with a glass electrode. Soil salinity was determined by two methods, the saturated paste extract method and the electrometric method. For the first method, the conductivity was measured in the saturated paste extract (ECe) corrected at a temperature T=25°C. Regarding the second method, the measurement was carried out in a suspension soil/distilled water ratio of 1/5 ($EC_{1/5}$) using a conductivity meter [18]. Cation and anion analysis was carried out using the same proportioning technique as for the irrigation water. The proportioning of the exchangeable cations was determined by atomic absorption spectrometry. The ESP is expressed by the following relationship [18]:

$$\mathrm{ESP} = \frac{\mathrm{Na}^+}{\mathrm{CEC}} \times 100 \qquad (2)$$

Where: Na^+= exchangeable sodium of the adsorbent complex expressed in milliequivalents for100 g of dry soil.

Mineralogical analysis was performed on a representative soil sample for each layer using X-Ray Diffraction (XRD) in order to identify and to quantify the minerals that constitute the soil [19]. This analysis was done on total powder samples of soil in the laboratory of the National Office of Mines (NOM), using a SIEMENS D5000 diffractometer [20].

III. RESULTS

A. Irrigation water quality

Results of the chemical characterization of the irrigation water are shown in Table I. The irrigation water is slightly alkaline and it is rich in soluble salts. The pH value is equal to 7.9; EC is about 7.2 dS/m at 25°C and TDS is almost 5.0 g/l. This water is characterized by the abundance of sulphates and sodium chlorides and the presence of potassium, calcium and magnesium and it is devoid of carbonates. Cations and anions are distributed according to the following order: $Na^+>Ca^{2+}>Mg^{2+}>K^+$ and $Cl^->SO_4^{2-}>HCO_3^-$.

Table I. Irrigation water characteristics

Parameter		**Value**	
pH		7.9	
EC (dS/m)		7.2	
TDS (g/l)		5.0	
Cations **(mg/l-meq/l)**	**Ca^{2+}**	280	14
	Mg^{2+}	120	9.87
	Na^+	1242	54
	K^+	24	0.61
Anions **(mg/l-meq/l)**	**SO_4^{2-}**	1344	28
	Cl^-	1775	50
	HCO_3^-	244	4
SAR		15.60	

Thus, this water has a chlorinated and sodic sulfated geochemical facies. The SAR value is about 15.6. These data classify the irrigation water in the C5S4 class according to the diagram of Riverside waters classification [21]. It is associated with a very high risk of salinization and alkalization. These results confirm those found by [22], indicating that irrigation water of the PIZ Zelba 1 has a chlorinated and sodic sulfated geochemical facies with a EC=6.9 dS/m and SAR=14.44. Therefore, this water may only be used for sandy soils and tolerant plants. It would have severe impacts according to the (FAO) classification.

B. Soil properties

The soil profiles reconstitution showed that the soil of the irrigation zone Zelba 1 is a deep isohumic brown soil with calcareous nodules. Vertical organization is the same everywhere and no significant difference appears in the soil profiles (Table II). However, some differences were observed in terms of texture, structure, color and degree of accumulation of calcareous. Texture analysis showed that the soil of the study zone presents a sandy-silt texture for the first 30 cm, a silty-sand texture at depths varying between 30 and 135 cm and a clay-silt texture at depths beyond 135 cm. The obtained values of the saturated permeability (K_{sat}) at the soil surface are between 8 10^{-6} m/s and 10^{-5} m/s. It is a permeable soil with K_{sat} values exceeding 5 10^{-6} m/s, which could be explained by the presence of a sandy-silt texture at the soil surface and/or multiplication of macropores just after tillage and backcrossing operations which improved the water infiltration rate [23]. Bulk density (BD) of this soil increased from 1.34 to 1.94 g/cm^3 with increasing depth (Table II). According to [24], BD values were considered as high since the BD for a sandy-silt to silty-sand varies from 1.35 to 1.4 g/cm^3 and it varies from 1.35 to 1.45 g/cm^3 for a clay-silt soil. Thus, the increase in BD with depth mainly depends on the variation of soil texture which becomes finer from the surface to deeper layers.

Table II. Soil physical characteristics

Depth (cm)	**Particle size (%)**					**Bulk density (BD)**
	C^a	**FS^b**	**CS^c**	**FS^d**	**CS^e**	
0-15	13	18	24	37	8	1.34
15-30	14	19	23	36	8	1.47
30-45	14	22	23	34	7	1.54
45-60	16	19	23	34	8	1.57
60-75	18	22	19	33	8	1.63
75-90	19	23	19	32	7	1.74
90-105	23	23	18	28	8	1.79
105-120	22	24	19	29	6	1.85
120-135	24	23	19	28	6	1.90
135-150	30	21	23	20	6	1.94

Note: ^{a}clay, ^{b}fine silt, ^{c}coarse silt, ^{d}fine sand and ^{e}coarse sand

- Carbonate content

The carbonate contents increased gradually with depth to reach 34% for the irrigated soil and 33% for the non-irrigated soil for which 23 and 16% respectively are classified as an active fraction (Fig.3a and 3b). This is confirmed by a gradual passage of the pseudo mycelium to calcareous stain and deeply to calcareous nodules. Generally, carbonate contents measured in the irrigated soil are slightly higher than those of the non-irrigated soil. Therefore, the use of brackish water has a little effect on the variation of this parameter in the soil of the irrigation zone.

- Organic matter content

The organic matter (OM, OC and N) content did not exceed 2%. In fact, the maximum value of OM is about 1.36%. It was detected in the surface layers of the irrigated soil and it is about 1.2% for the non-irrigated soil. Besides, a decrease in this content with depth was noted (Fig.3c, 3d, and 3e). It may suggest that the occupation of the irrigation zone by forage crops particularly alfalfa which favored the accumulation of OM in soil surface layers after irrigation with brackish water. In addition, the decrease in OM content with depth reflects its decomposition and rapid mineralization of OM by the microorganisms. Finally, the slight variation of the OM content observed between the two soils, especially from a depth of 60 cm indicate that the use of brackish water does not have a significant effect on the variation of this parameter with depth. In order to better understand the evolution of the OM in soils of the irrigation zone, the C/N ratio was calculated (Fig.3f). In all soils, the C/N ratio decreased from the surface to the deep layers, with some excessive values observed particularly in the layers (15-30, 30-45 and 60-75 cm) for the irrigated soil and the layer (15-30 cm) for the non-irrigated soil. Indeed, this ratio varied from 6.7 to 4.25 and from 7 to 5.8 for the irrigated and non-irrigated soils respectively. This would imply that low values of C/N ratio observed in irrigated and non-irrigated soils are mainly due to the low OM soil content, especially in the deepest layers.

- Cation Exchange Capacity

Soil chemical characterization showed that mean CEC values increased with depth. They varied from 6.7 to 26 meq/100 g (table III). It is noted that the CEC variation is not associated with the OM content variation. Indeed, OM values decrease from 1.36 to 0.30% for irrigated soil, while the CEC was shown to increase with depth. This could be related to the soil texture variation, particularly its clay content. These results confirm those found by [25] indicating that the CEC is strongly correlated with the clay content.

- Soil pH

The pH profiles showed that soils of the irrigation zone are generally alkaline, with an average pH of about 8.7. In fact, pH values decreased with depth, from 8.66 (±0.17) to 8.4 (±0.18) for the irrigated soil and from 9.2 (±0.19) to 8.6 (±0.23) for the non-irrigated soil. The comparison of these profiles showed that the mean values of pH for the irrigated soil with brackish water are generally lower. However, pH values are slightly higher in the soil surface (Fig.3g).

- Soil salinity

Soil salinity was studied using two methods: the saturated paste extract method (ECe) and the electrometric method ($EC_{1/5}$). Indeed, mean ECe values varied from 5.3 (±0.35) to 11.9 (±0.15) dS/m for the irrigated soil and from 6.9 (±0.49) to 12.2 (±0.9) dS/m for the non-irrigated soil (Fig.3h). These are descending profiles with a trend of the increase in soil salinity with depth, where the ECe values are multiplied by two and the soil texture becomes finer. Based on [18], classification, the soil is considered saline with ECe values exceeding 4 dS/m. Moreover, these results showed that the measured ECe are more important for the non-irrigated soil than those for the irrigated with brackish water.

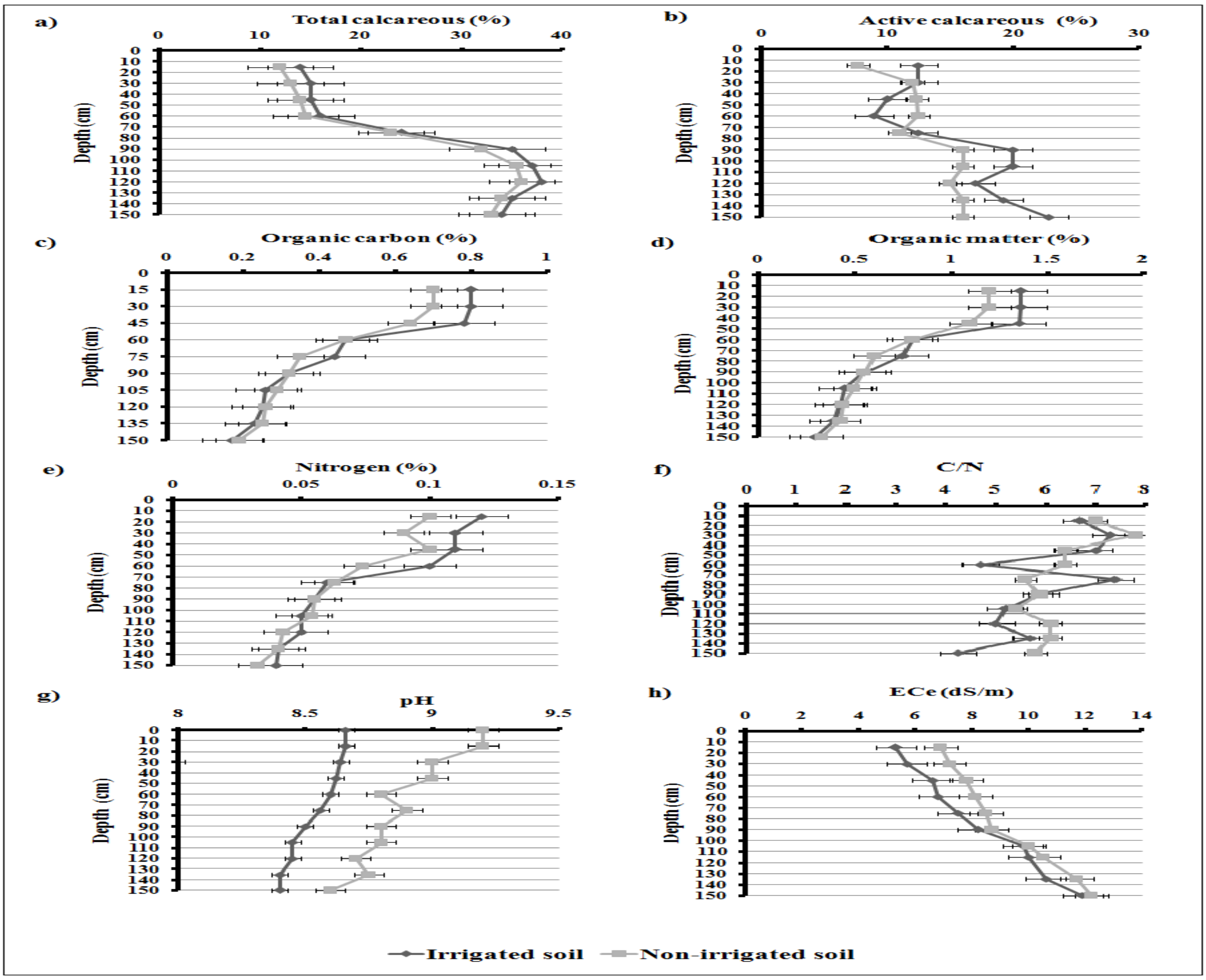

Fig. 3. Chemical characteristics of irrigated and non-irrigated soils

The relationship between salinity and soil texture was examined by correlating ECe values and clay content (Fig.4). A significant positive correlation (r=0.98) was obtained. This clearly confirms that the increase of soil salinity with depth corresponds to an increase of the fine fraction in the soil. This correlation has been reported by several authors as [10].

Soil salinity was measured at the soil surface of different lots, using the electrometric method ($EC_{1/5}$). These measurements were performed in order to study the impact of the use of brackish water in irrigation (Fig.5). In fact, the $EC_{1/5}$ values varied from 1.45 to 2.1 dS/m for the non-irrigated soil, indicating a saline soil according to the classification of [18].

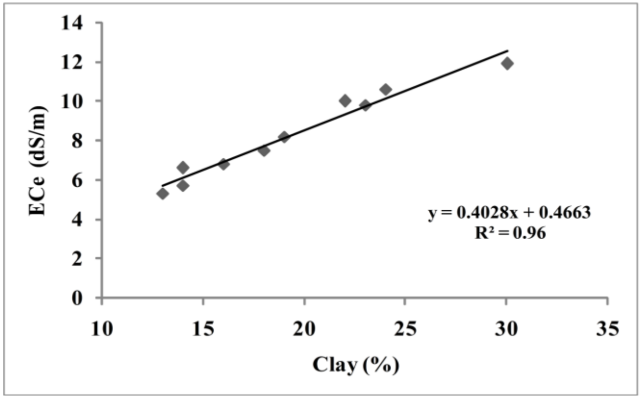

Fig. 4. Correlation between ECe and the fine fraction in the irrigation zone

The salinity values varied from 0.7 to 1.3 dS/m for the irrigated soil, which corresponds to moderately saline classes. The standard deviations between values corresponding to both soils are low. They vary between 0.48 and 0.64. Therefore, these results showed that the $EC_{1/5}$ values measured at the soil surface are more important for the non-irrigated soil than that irrigated with brackish water.

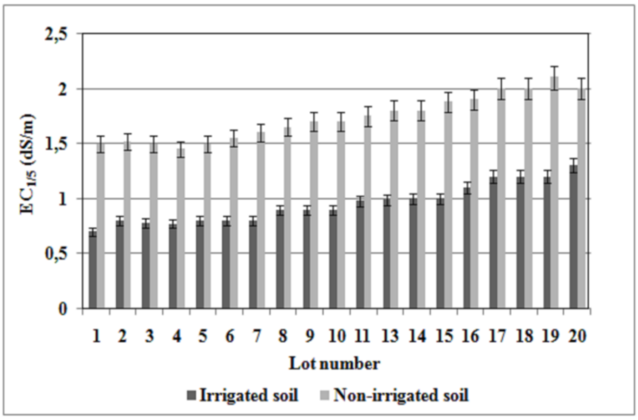

Fig. 5. Variation of the $EC_{1/5}$ in the soil surface

- Soil sodicity

The richness of the soil adsorbent complex in sodium ion and the susceptibility of the soil structure degradation are characterized by the rate of sodium adsorption ratio of the soil solution (SAR) and the exchangeable sodium percentage (ESP) when they exceed the thresholds of 10 and 15% respectively [26].

Table III revealed that soluble sodium is the major cation and its concentration is largely higher than that of calcium, magnesium and potassium. It varied with depth from 65 to 30 meq/l. Soluble cations are distributed according to the following order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. Besides, a decrease in these elements, with depth was observed. This decrease may be explained by the interaction between the soil solution chemical composition and the clay-humic complex, especially for the case of calcium and sodium. The chloride is the major anion followed by the sulfate ion. These two elements varied with depth from 60 to 91 meq/l and from 44 to 28 meq/l respectively. Soluble anions are distributed according to the following order: $Cl^- > SO_4^{2-} > HCO_3^-$. Thus, this soil has a chlorinated and sodic sulfated geochemical facies and it is comparable to that of the irrigation water. Obtained SAR values are greater than 10 and reach a maximum value of the order of 32 in layers of (90-105 cm) and (120-135 cm).

Table III revealed that the adsorbent complex is substantially saturated by exchangeable calcium which increased with depth from 6 to 8.8 meq/100 g. The exchangeable sodium increased with depth from 1.3 to 7.5 meq/100 g. The exchangeable potassium is present in very small quantity compared to other cations. This element decreased with depth from 1.1 to 0.3 meq/100 g. The ESP values observed along the soil profile exceed 15%. These values increased from 19.4 to 28.85% from the surface to deeper layers.

In fact, the dominance of exchangeable calcium compared to other cations is related to its natural origin (calcareous crust). The ESP variation with depth behaved in a same way than that of the CEC and the exchangeable sodium. Therefore, the increase in clay fraction with depth, leads to a high CEC deep in the soil and thus promotes the exchangeable sodium fixing on the soil adsorbent complex. This element tends to alkalize the soil complex by the phenomena of exchange and therefore conduct the irrigation zone to fail if certain precautions are not taken into consideration. For the exchangeable potassium, its low content may weaken the soil fertilizing capacity. For this purpose, additional contributions of this element would be needed to fill the deficit.

Table III. Soil chemical characteristics

Depth (cm)	**Ionic balance (meq/l)**							**SAR**	**Exchangeable cations (Meq/100 g)**				**ESP (%)**	**CEC**
	Major cations				**Major anions**									
	Ca^{2+}	**Mg^{2+}**	**Na^+**	**K^+**	**SO_4^{2-}**	**Cl^-**	**HCO_3^-**		**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**		
15	10	8.14	65	0.6	44	60	3.6	21.85	6	2	1.3	1.1	19.4	6.7
30	7.7	6.91	44	0.65	45	62	4	16.28	6.2	2.1	1.5	1.1	20.83	7.2
45	5	6.25	34	0.5	40	60	2.3	14.34	6.26	2	3	1	25.42	11.8
60	4.33	3.95	30	0.62	43	55	2.6	14.74	7.55	3	3.7	1.3	25	14.8
75	4	2.96	32	0.4	44	56	2	17.15	8	3.1	4.1	0.55	25.3	16.2
90	3.33	2.03	45	0.3	48	88	3	27.49	8.1	3	4.5	0.6	25	18
105	2	1.56	43	0.3	50	90	3	32.23	8.35	2.9	4.9	0.6	25.65	19.1
120	2.01	1.55	36	0.2	30	89	2	26.96	8.68	2.2	5.2	0.55	26	20
135	0.8	1.06	31	0.2	27	88	2.2	32.15	8.75	2.3	5.9	0.3	28	21
150	2	0.9	30	0.1	28	91	2	24.91	8.8	2.3	7.5	0.3	28.85	26

Note: CEC is expressed in Meq/100 g.

- Soil mineralogy

The soil mineralogical characterization revealed mainly the presence of quartz and calcite (Fig.6). This Fig also showed that quartz content decreased slightly with depth in favor of the calcite content which increased with depth. Indeed, quartz content varied from 85 to 67.2% and calcite content varied from 11.64 to 32.25%. This mineralogy is explained by the presence of calcareous stain and deeper of calcareous nodules. Thus, it confirms the results of analysis of the carbonate contents mentioned previously indicating an increase of total and active calcareous with soil depth. Similar results were found by [27] with a calcic soil characterized by the presence of calcareous stain and calcareous nodules in depth and analyzed by the X-Ray Diffraction (XRD) method. Feldespath was also detected and the percentage did not exceed 5% with a total disappearance in layers 105-120 cm and 135-150 cm. Moreover, in different soil layers the phyllosilicates appear, but in very small quantities.

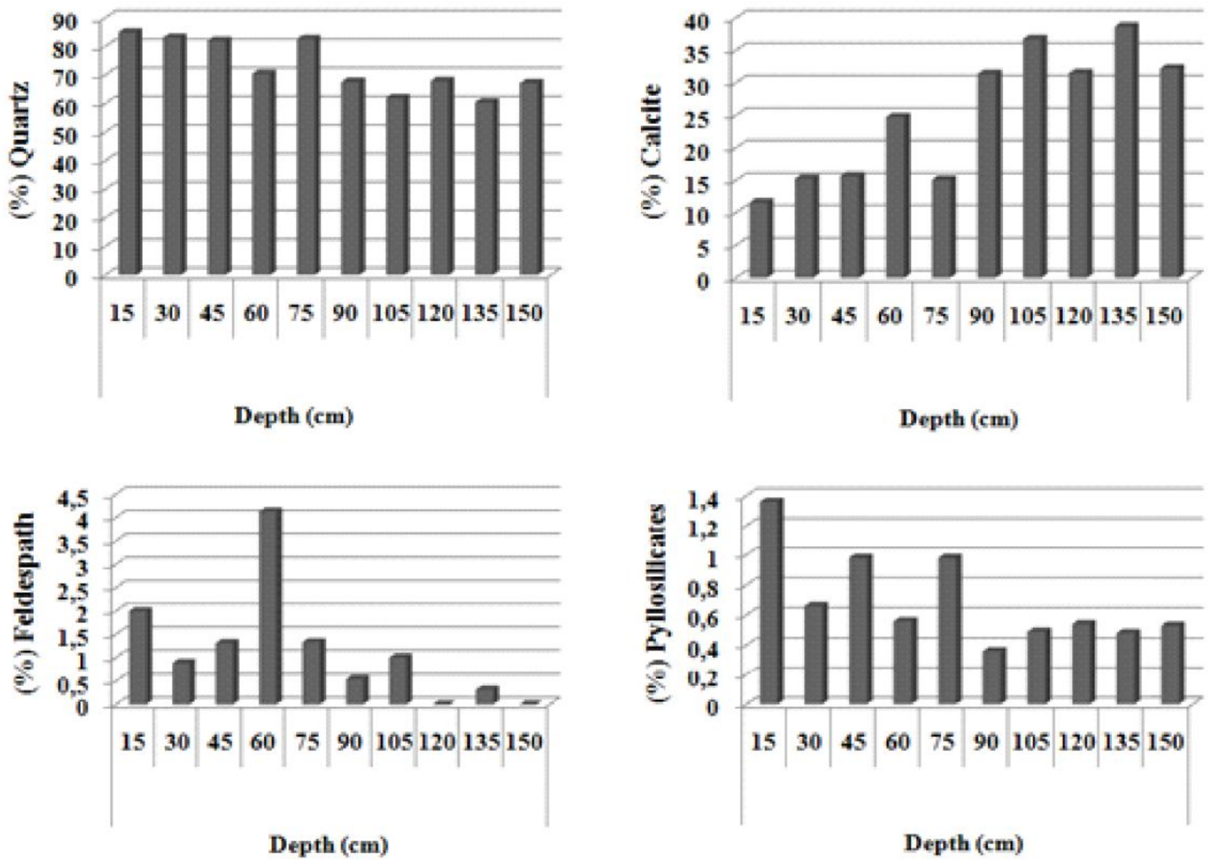

Fig 6. Soil mineralogical characterization

IV. DISCUSSION

Soil salinity in the irrigation zone is the result of the cumulated effects of an arid climate, where precipitations are rare and irregular and the waters used in irrigation are highly charged with soluble salts. The comparison between soil profiles showed that the salinity observed in the non-irrigated soil is higher than that observed in the soil irrigated with brackish water. This would imply that irrigation resulted in a slight decrease of soil salinity, explained by the leaching action of the irrigation water. The descendant movement of salts could be due to the leaching of salts to the deep layers following the irrigation and the rains recorded in Mai and June (2011) with a total precipitation of about 85.5 mm. These results confirm those found by Ben Hassine in 1992 and 1993 [28], indicating that soil salinity measured in this irrigation zone and evaluated by the same method increased with depth. However, these results contradict those found by [29], who studied the soil salinity variation with depth between irrigated and non-irrigated soil in the irrigation zone of Segdoud (Southwest Tunisia). In fact, these results indicated a descendant movement of salts in the irrigated soil whereas in the non-irrigated soil, results showed an ascendant movement of salts. The presence of a salty and near-surface groundwater and the sandy-silt soil of the irrigation zone of Segdoud are favorable to the salts mobilization by capillary rising in the absence of irrigation [29].

Indeed, soils of the irrigation zone Zelba 1 (isohumic) are characterized by a sandy-silt texture, a good permeability and a low CEC at the soil surface. Thus, these soils are characterized by a good water infiltration rate and a low hydric retention capacity, favorable characteristics for the transfer of soluble salts towards the deepest layers by vertical leaching, where the soil texture becomes finer. The deep drainage operations are therefore, essential to avoid the concentration of soluble salts in the deep layers, which reduce the productive potential of irrigated lands. For the non-irrigated soil, the slightly increase in the soil salinity observed throughout the soil profile compared to that of the irrigated soil profile is essentially due to the arid climatic conditions producing a very intense evaporation during the summer season.

The use of this water in irrigation has also an effect on soil alkalinity. It resulted in a decrease in the pH of these soils and also resulted in improving the physical properties of the irrigated soil. Moreover, the leaching of the active calcareous, responsible for the alkalinity of the soil, by irrigation water was also an invoked explanation [30]. Concerning the decrease in the pH with depth, it is not clearly associated with the variation of the contents of total calcareous and active calcareous. Certain authors explain this decrease by the oxidation of the soil organic matter and the nitrification of the soil ammonium [31].

Regarding soil sodicity, sodium adsorption ratio and exchangeable sodium percentage values observed along the soil profile are greater than 10 and 15% respectively. Thus, the use of brackish water was shown to have a significant effect on the soil by the accumulation of soluble sodium in this soil either in the soil solution or on the absorbent complex. This accumulation may degrade the soil physical properties and affects its structural stability causing, a clay deflocculation and soil destruction by sodisation in the long terms.

IV. CONCLUSION

The PIZ Zelba 1 has undergone irrigation by brackish water since its creation in 1986. The soil physical characterization revealed that the texture and the permeability of the soil surface conferred to the soil a very important filtering power. In the deep layers, where the texture becomes finer, water diffused slowly into the soil and it is retained at a potential capillarity relatively high, which increased the risk of accumulation of salts. Soil chemical characterization showed that soils are quite rich in carbonates where contents increase gradually with depth. The mineralogical analysis confirmed these results. The organic matter content decreased from the soil surface to the deep layers, reflecting a rapid mineralization of organic matter. This process plays an important role in the enhancement of the process of soil salinization. Whereas, the cation exchange capacity variation is not associated with the organic matter content variation. The increase in cation exchange capacity with depth promotes the exchangeable sodium fixing on the soil adsorbent complex and thus increases the risk of soil sodisation.

Regarding the soil alkalinity, the use of this water in irrigation has also an effect on pH variation. It resulted in a decrease in the pH of the irrigated soil in comparison with the non-irrigated soil. Moreover, the leaching of the active calcareous, responsible for the alkalinity of the soil, by irrigation water was also an invoked explanation. The monitoring of the variation in the soil ECe with depth showed a saline soil with values exceeding 4 dS/m. This monitoring also showed an increasing gradient of salts toward the deep layers due to the salts leaching, following the irrigation. The spatial evolution of the soil salinity showed that the values of the $EC_{1/5}$ are more important in the non-irrigated soil. Surface layers, characterized by the sandy-silt texture, have undergone desalinization and infiltration of soluble salts from irrigation water. Concerning the soil sodicity, sodium adsorption ratio and exchangeable sodium percentage values observed along the soil profile exceed accepted thresholds. Therefore, the use of water with a very high risk of salinization and alkalization could increase the risk of soil salinization and sodisation in the long terms.

In this regards, the use of good-quality water in irrigation may initially improve the soil salinity and sodicity. Moreover, the use of crops varieties that tolerate soil salinity is essential. Chemical amendment including gypsum ($CaSO_4 \cdot 2H_2O$) is a good solution by improving soil properties and finally providing good productivity. In fact, gypsum provides calcium, molecule necessary for the clay flocculation in the soil. This latter is necessary, in order to give the favorable soil structure for root growth and the movement of water and air. In addition, the deep drainage installation is essential in order to avoid the concentration of soluble salts in the deep layers. Finally, the continuous control of soil salinity and sodicity in the irrigation zone is necessary. It would be necessary to push the stages of observations by multiplying the methods of monitoring of the soil properties.

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