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Salinity Temporal Evolution Assessment under Mediterranean Conditions

Samir Hadj-Miloud[1], Abdelkarim Ouamerali[1], Becherki Mohamed Aichouni[1]

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ABSTRACT

Background: The present study aims to study the temporal evolution of the salinity of three profiles of Solonchaks which are in the region of Rélizane (Algeria). The aim is to determine the temporal changes in salinity between 2010 and 2014, by comparing saline profiles to determine the direction and intensity of variation in soil salinity.

Methods: The experiment was carried out on three soil profiles (Solonchaks) which are located in the perimeter of the Mina which is located in the Bas-Chélif.

Result: The study of the temporal evolution of salinity showed that the majority of horizons underwent desalination between the 2010 and 2014 campaign. This desalination occurred at a speed between 3.67 and 10.74 dS m^{-1} per year. This would be due to a partial leaching of salts from the surface horizons during the rainy season. The soils studied are marked by a higher salinity during the 2010 compared to the 2014 campaign. The principal component analysis (PCA) reveals that the chemical elements of the soil solution have the most weight on the variability of salinity, and the Wilcoxon test reveals that the difference between the EC of the 2010 campaign and that of 2014 is significant.

Key words: Salinity, Soil solution, Solonchaks, Temporal evolution.

INTRODUCTION

Soil salinity is recognized as an important indicator of soil quality (Brady and Will 2008; Litalien and Zeep, 2020). It largely dominates land use strategies, directly affecting decision-making for effective land management (Eswaran *et al*., 2019; Taghizadeh-Mehrjardi *et al*., 2021). Salinization is a common pedogenetic process in Algerian soils (Daoud, 1993). Moreover, soil salinization is an important process, especially in arid and semi-arid areas (Saidi *et al*., 2004), which leads to the degradation of physical, chemical and biological properties of soils. The consequences of this degradation are the reduction of soil fertility, which leads to a reduction in crop yields, and sometimes the disappearance of plant cover.

Moreover, according to Abbas *et al*. (2011) found that globally, soil salinization is spreading at a rate of up to 2 million hectares per year. Vast in area, approximately 77 million hectares of land are salinized due to human activity, of which 58% is irrigated (Metternicht and Zinck, 2003).

However, the Solonchaks of Rélizane have a relatively higher degree of belonging with the Calcisols than with the Gypsisols whatever the season and the year considered (Hadj-Mloud and Djili, 2021; Hadj-Miloud *et al*., 2018).

Algeria with more than 20% of irrigated soils affected by salinization (Douaoui and Hartani, 2007), is among the countries most threatened by this problem. This requires careful monitoring of the state and temporal variation of soil salinity to curb the trends of this problem and ensure sustainable land management.

This work focuses on the study of the temporal evolution of the salinity state of the Solonchaks located in the Rélizane region. It is therefore:

[1]Ecole Nationale Supérieure Agronomique (ENSA, ES1603), El-Harrach, Algeria.

Corresponding Author: Samir Hadj-Miloud, Ecole Nationale Supérieure Agronomique (ENSA, ES1603), El-Harrach, Algeria.
Email: samir.hadjmiloud@edu.ensa.dz

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- Characterize the soil solution, define the saline profiles and determine the chemical facies of the soil solutions.
- Determine temporal changes in salinity between 2010 and 2014, comparing saline profiles to determine the direction and intensity of soil salinity variation.

MATERIALS AND METHODS

Study area

The soils studied are located in the Relizane region, is known for its two large irrigated perimeters, the perimeter of La Mina and that of Bas-Chéliff.

It is in this context that we have studied three soil profiles (P1 and P2) which are present in the perimeter of the Mina and another profile (P3) which is located in the perimeter of Bas-Chélif, more precisely in the research station at Hmadna (Fig 1).

The geographical coordinates of the studied profiles are presented in the Table 1.

The climate is semi-arid (253 mm rain/year), temperate in winter with very strong potential evapotranspiration (1500 mm/year).

The choice of profiles is based on the diagnostic criteria of Solonchaks according to IUSS Working Group WRB (2014).

This study was conducted at the Ecole Nationale Supérieure Agronomique, El-Harrach, Algeria. January, 2021.

Methodology

The first step is to characterize the soil solution, to define the salt distribution profiles in the soil, and to determine the chemical facies of the soil solutions. Then, it will be a question of studying the temporal evolution of salinity between the wet season of 2010 and 2014 in the irrigated perimeters of Bas-Chéliff and Mina. This monitoring is carried out on three reference profiles of Solonchaks identified by HadjMiloud (2010). To do this, we calculated the rate of salinization by profile. The average EC of the profile is calculated according to the following formula:

$$\frac{\Sigma\ (\text{EC of each horizon} \times \text{Horizon thickness})}{\text{Profile thickness}}$$

The difference in the average salinity of the profiles is obtained by the difference between the values of the EC for the wet season of the 2014 campaign and that of the EC for the 2010 campaign [EC (2014)-EC (2010)]. The salinization rate is obtained by dividing the difference by time (4 years).

In order to better analyze the data, we used PCA (principal component analysis). This analysis allows us to determine the anions and cations of the soil solution that have the most influence on the variation in salinity.

Subsequently, we performed non-parametric tests (Wilcoxon test). This test reveals whether the differences between the EC values of the 2014 campaign and that of 2010 are significant or not.

RESULTS AND DISCUSSION

The soil solution (campaign 2010)

The descriptive statistics of the examined parameters of profile 1 are presented in Table 2.

Electrical conductivity

Table 2 and Fig 2 show that the surface horizon (Anz) is characterized by high salinity (43.8 dS m^{-1}) (USSL, 1954). However, this EC is relatively weak compared to the other horizons of the profile. This phenomenon may be due to rain-induced salt leaching, which was procured in the subsurface horizon, leading to an increase in EC (1.6 dS m^{-1}). On the other hand, we note an increase in the salinity of the two horizons BCnz and Cnz1, reaching values of 61.6 and 57.5 dS m^{-1} respectively.

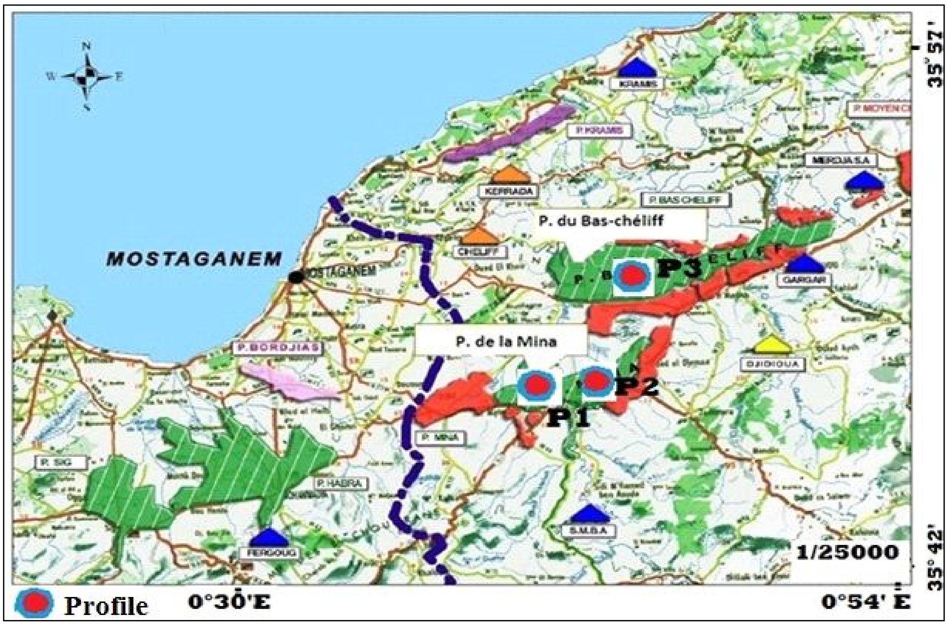

Fig 1: Profiles location map (red spots).

Table 1: Profiles location.

Profiles	Geographic coordinates	Location
1	Longitude 0° 29′31.2″E; Latitude 35° 44′17.0″N	Mina
2	Longitude 0° 33′22.0″E; Latitude 35° 47′44.33″N	Mina
3	Longitude 0° 44′59.6″E; Latitude 35° 57′47.5″N	Bas-Chéliff

pH

Table 2 indicates a pH value greater than 8 with an average value which is around 8.2. These values show a relatively alkaline soil reaction, the pH is homogeneous in the profile.

Cations

Among all the cations in the soil solution (Fig 3), the Na^+ cation is the most represented with an average rate of 48% and a concentration which varies between 212.7 meq l^{-1} and 370.78 meq l^{-1}.

Anions

The main ion in the soil solution is Cl^- (Fig 4). It represents on average 93% of the total amount of anions with values that vary between 405 meq l^{-1} and 630 meq l^{-1}.

Profile 2

The descriptive statistics of the studied parameters of profile 2 are indicated in Table 3.

Electrical conductivity

The extreme values of salinity in profile 2 vary between 10.7 dS m^{-1} and 56.8 dS m^{-1} with an average of 32.46 dS m^{-1}.

These values demonstrate that profile 2 is highly salty. Salinity increases steadily from the surface horizon to the depth horizon, reaching values of 10.7 and 56.5 dS m^{-1} respectively (Fig 5). The result indicates that the salt profile is descending.

pH

The pH values vary between 7.13 and 7.8 with an average of 7.43 (Table 3). These values correspond to a relatively alkaline soil reaction.

Cations

With concentrations varying between 250 and 950 meq l^{-1}, Na^+ occupies on average 46% of the cations in the soil solution (Fig 6).

Table 2. Descriptive statistics of the pH and EC of profile 1.

Parametres	pH (1:2.5)	EC (dS m^{-1})
Maximum	8.44	86.20
Minimum	8.17	43.80
Mean	8.29	63.66
SD	0.13	15.62
CV (%)	1.56	24.53

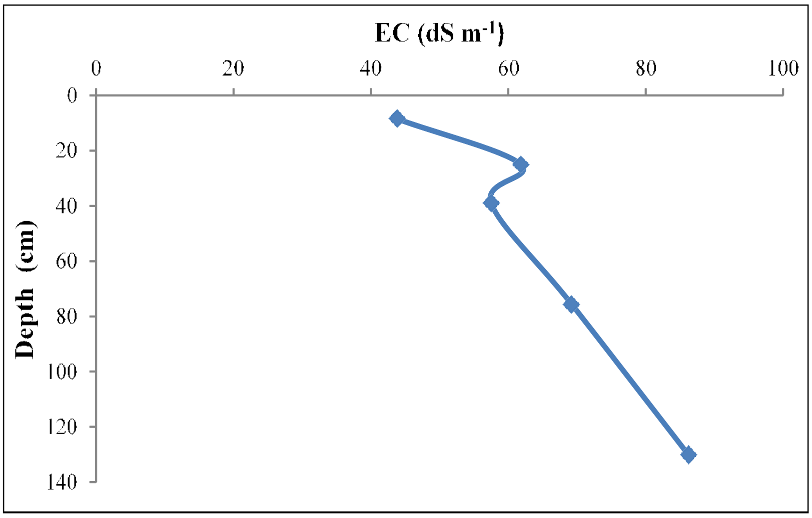

Fig 2: Distribution of salts according to the depth of profile 1.

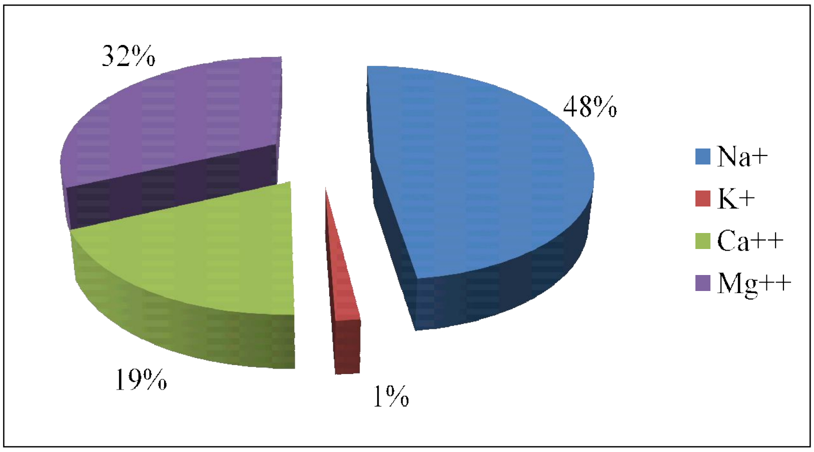

Fig 3: Average distribution of cations in the soil solution of profile 1.

Anions

The predominant ion in the soil solution is Cl^-. It represents on an average 58% of the total amount of anions with values that vary between 60 meq l^{-1} and 540 meq l^{-1} (Fig 7).

Profile 3

The descriptive statistics of the examined parameters of profile 1 are presented in Table 4.

Electrical conductivity

Table 4 and Fig 8 show that the surface horizon has a low salinity compared to the other horizons in the profile (EC= 7.21 dS m^{-1}). The salinity then increases at the level of the Bgnz1, Bgnz2 and Bgnz3 horizons to reach values which are respectively 22.4 dS m^{-1}, 25.8 dS m^{-1} and 35 dS m^{-1} (Fig 9). The extreme salinity values in profile 3 vary between 7.21 dS m^{-1} and 35 dS m^{-1} with an average of 24.22 dS m^{-1} (Table 4).

pH

The pH values vary between 7.06 and 7.75 with an average of 7.27 (Table 4). These values indicate a relatively alkaline soil reaction. The pH variation in the profile remains low with regard to the coefficient of variation (CV=3.83%).

Cations

Among all the cations in the soil solution (Table 4 and Fig 9), the Na^+ cation is the most abundant with an average rate of 74%. Ca^{++}comes in second position with a rate of 17% and contents that vary between 25.67 meq l^{-1} and 48.27 meq l^{-1}.

Table 3: Descriptive statistics of the pH and EC of profile 2.

Paramètres	pH (1:2.5)	EC (dS m^{-1})
Maximum	7.85	56.80
Minimum	7.13	10.70
Mean	7.43	32.46
SD	0.14	7.55
CV (%)	4.30	51.99

Table 4: Descriptive statistics of the pH and EC of profile 3.

Paramètres	pH (1:2.5)	EC (dS m^{-1})
Maximum	7.75	35.00
Minimum	7.06	7.21
Mean	7.27	24.22
SD	0.12	10.65
CV (%)	3.83	43.95

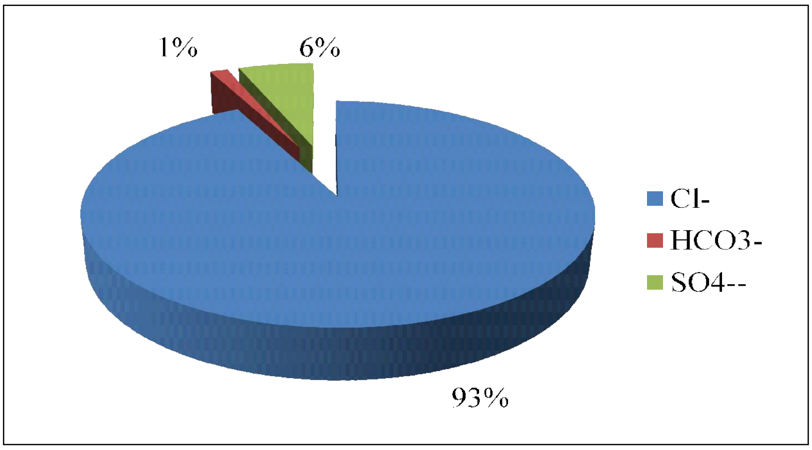

Fig 4: Average distribution of anions in the soil solution of profile 1.

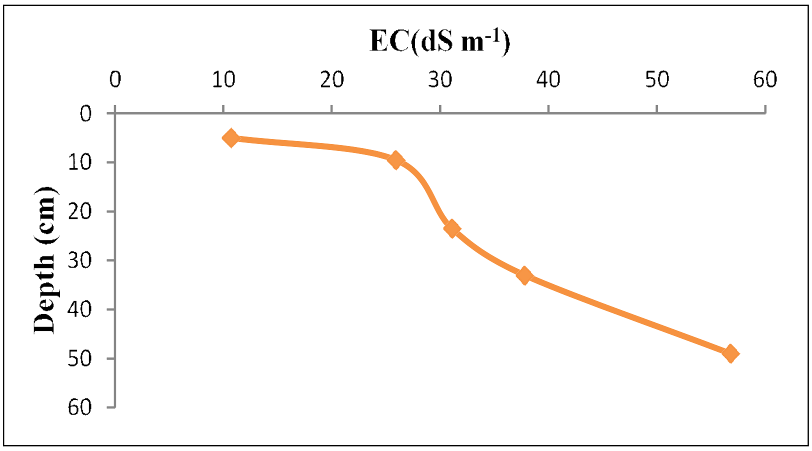

Fig 5: Distribution of salts according to the depth of profile 2.

Anions

The predominant ion in the soil solution is Cl^- (Table 5 and Fig 10). It represents on average 82% of the total amount of anions with values varying between 60 meq l^{-1} and 320 meq l^{-1}.

The chemical facies

The Piper diagram (Fig 11) showed that the majority of the chemical facies of the compound soil solutions is of the sodium chloride type. However, we note the presence of the following chemical facies: the magnesian chloride type, chloride without dominance of one of the cations and the sodium hyperchloride facies.

These chemical facies favor that the soils consumed evolve according to the neutral saline route with a dominant chloride content (Marlet and Job, 2006).

Temporal evolution of salinity

The study of the temporal evolution of the salinity studied between two companions consists in comparing the saline profiles of the year 2010 and 2014.

Comparison of saline profiles between the two companions

The comparative study of salt distribution profiles between the two companions focused on 3 profiles (P1, P2, P3). These profiles present complete data for all horizons concerning the 2010 campaign. The comparison of data from 2010 and that of 2014 will make it possible to identify the temporal evolution of salinity over a period of 4 years. Comparison of salt profiles reveals that salinity decreased in all profiles in 2014 compared to 2010 in the three profiles 3 (Fig 12, 13 and 14). Only the surface horizon of profile 3 underwent a slight increase in surface salinity during the year 2014 (EC=3.96 dS m^{-1}) (Fig 14).

Evolution gradient of salinity

The comparison of the salinity levels between the two companies will make it possible to determine the direction of the evolution of the salinity of each horizon of the soil.

Evolution gradient of salinity per horizon

Table 5 shows that globally all the horizons underwent desalination in 2014, with a speed between 1.27 and

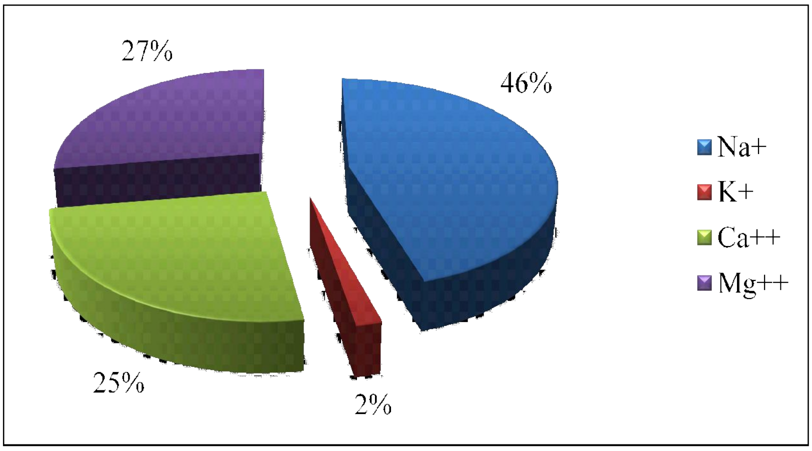

Fig 6: Average distribution of cations in the soil solution of profile 2.

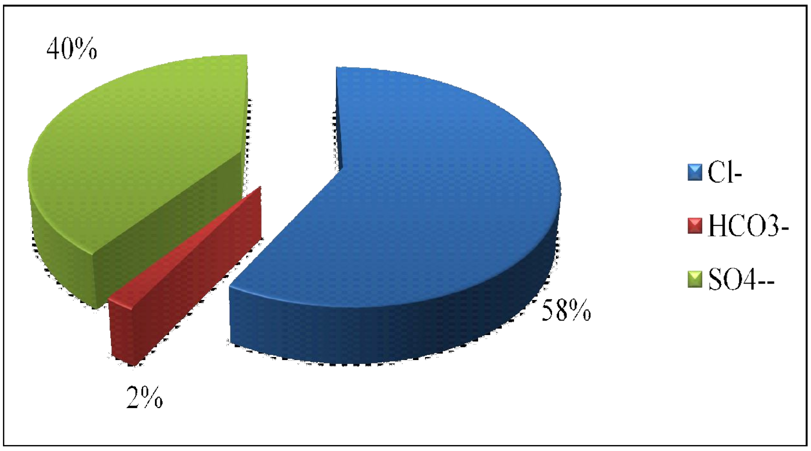

Fig 7: Average distribution of anions in the soil solution of profile 2.

33.07 dS m^{-1} per year. Only the surface horizon (H1) of profile 3 which recorded salinization with a rate of 0.99 dS m^{-1} per year.

Furthermore, the surface horizons of profiles 1 and 2 show desalination which occurred at a rate of 9.14 and 33.07 dS m^{-1} per year respectively.

The subsurface horizons (H2) showed desalination at a rate varying between 1.52 and 12.42 dS m^{-1} per year for the three profiles.

The depth horizons (H3, H4 and H5) show desalination with a rate varying from 1.27 to 10.87 dS m^{-1} per year for the three profiles.

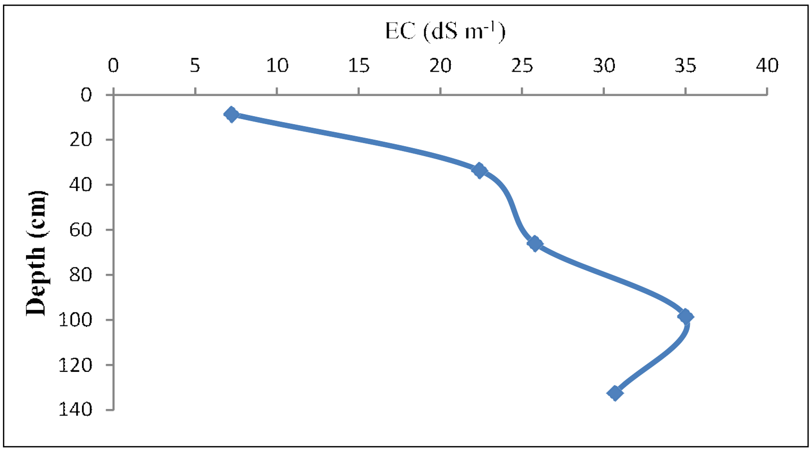

Fig 8: Distribution of salts according to the depth of profile 3.

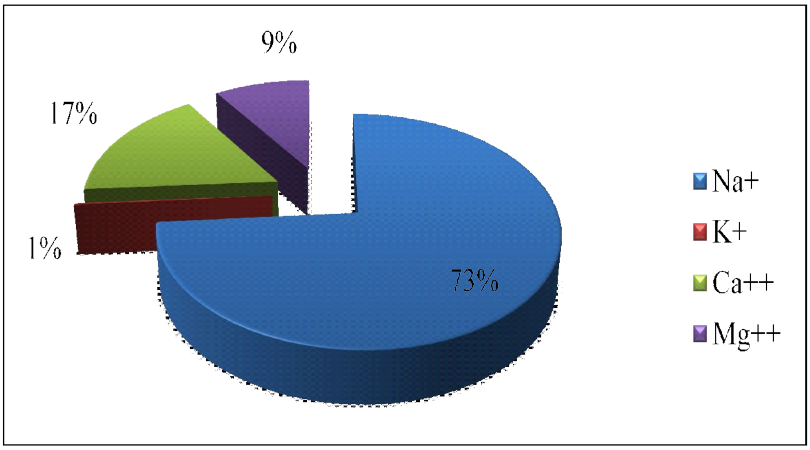

Fig 9: Average distribution of cations in the soil solution of profile 3.

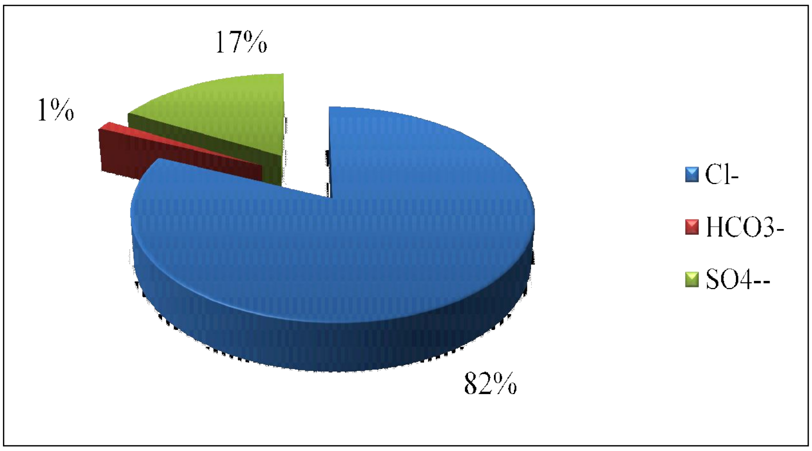

Fig 10: Average distribution of anions in the soil solution of profile 3.

Evolution gradient of salinity by profile

Table 6 shows that the three profiles underwent desalination between 2010 and 2014. This desalination occurred at a rate between 3.67 and 10.74 dS m^{-1} per year.

In addition, we performed a non-parametric test (Wilcoxon test). This test reveals whether the differences between the EC values of the 2014 campaign and that of 2010 are significant or not. The results of the test (Table 7)

Table 5: The difference and speed of salinization between 2010 and 2014 by horizon of the profiles.

Horizons	profiles	EC (dS m^{-1}) (2010)	EC (dS m^{-1}) (2014)	EC (2014)-EC (2010) (dS m^{-1})	salinity gradient in dS m^{-1} per year
H1	P1	43.8	7.23	-36.57	-9.14
	P2	143	10.7	-132.3	-33.07
	P3	3.65	7.21	3.96	0.99
H2	P1	61.6	11.92	-49.68	-12.42
	P2	32	25.9	-6.1	-1.52
	P3	45.3	22.4	-22.9	-5.72
H3	P1	57.5	18.49	-39.01	-9.75
	P2	75.1	31.1	-44	-11
	P3	50.3	25.8	-24.5	-6.12
H4	P1	69.2	64.1	-5.1	-1.27
	P2	72	37.8	-34.2	-8.55
	P3	42.2	35	-7.2	-1.8
H5	P1	86.2	42.7	-43.5	-10.87
	P2	94.2	56.8	-37.4	-9.35
	P3	44.7	30.7	-14	-3.5

Table 6: The difference and average salinization rate between 2010 and 2014 of the three profiles.

Profiles	Average profile EC (dS m^{-1}) (2010)	Average profile EC (dS m^{-1}) (2014)	The difference in EC between the two EC periods (dS m^{-1})	Salinization rate (dS m^{-1} per year)
P1	69.11	42.73	-26.38	-6.59
P2	78.66	35.7	-42.96	-10.74
P3	40.82	26.11	-14.71	-3.67

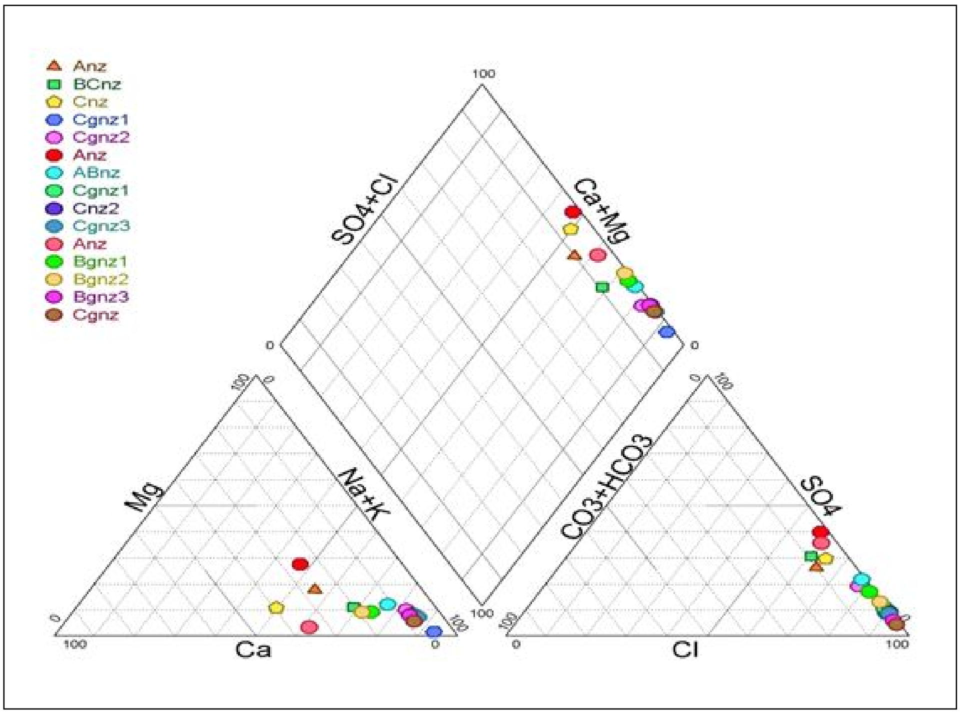

Fig 11: Piper diagram of the 2014 campaign samples.

reveal that at the significance level α=0.05 (p-value < 0.05), we can reject the null hypothesis, of the absence of significant difference between EC of the samples studied. So the difference between the EC of the 2010 campaign and that of 2014 is significant.

Multidimensional analysis of the chemical composition of the soil solution

We applied the principal component analysis (PCA), in order to know the elements of the soil solution which have the most weight on the variation of the EC.

EC PCA and soil solution ions

From Fig 15, the F1 axis extracts 59.58% of the inertia from the point cloud. On the F2 axis, the residual inertia that it extracts is 20.43%. Most of the information is represented by the F1 and F2 axis.

The first axis is formed by the contribution of the following variables: Cl- (r = 0.98), SO4-- (r = 0.79), EC (r = 0.99), Na^+ (r = 0.96), Mg^{++} (r = 0.96) and Ca^{++} (r = 0.26) (Table 8). However, the F2 axis is formed by the contribution of the variables: Ca^{++} (r =0.79) and K^+ (r = -0.65). However, the elements of the solution which contribute the most in the formation of the axes are Cl^-, Na^+, Mg^{++} and SO4--. This is explained by the fact that these elements come from more soluble species compared to the other elements (Hadj-Miloud, 2019).

The evaporated climate of this region (ETP 1500 mm/ year), associated with a water deficit, combined with a

Table 7: Statistical results of the Wilcoxon Test.

Paramètres	Values
Esperance	60
Variance	310
valeur observée	2.55
valeur critique	1.96
p-value bilatérale	0.01
α	0.05

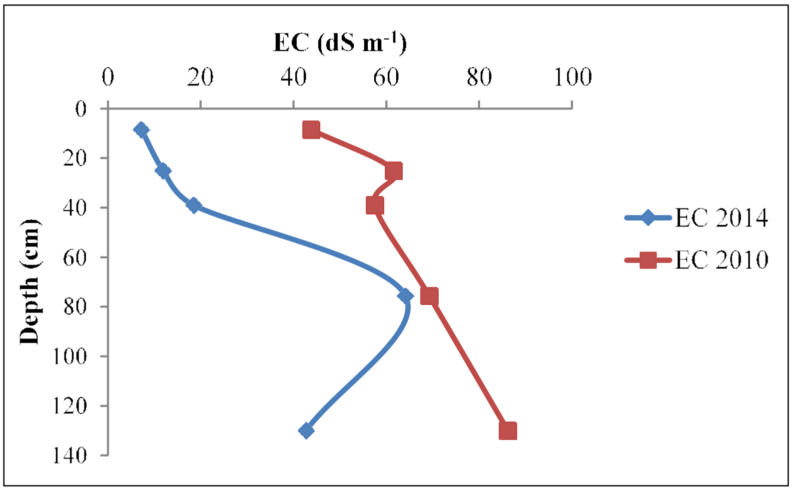

Fig 12: Profile 1 salt distribution for the two campaigns (2010 and 2014).

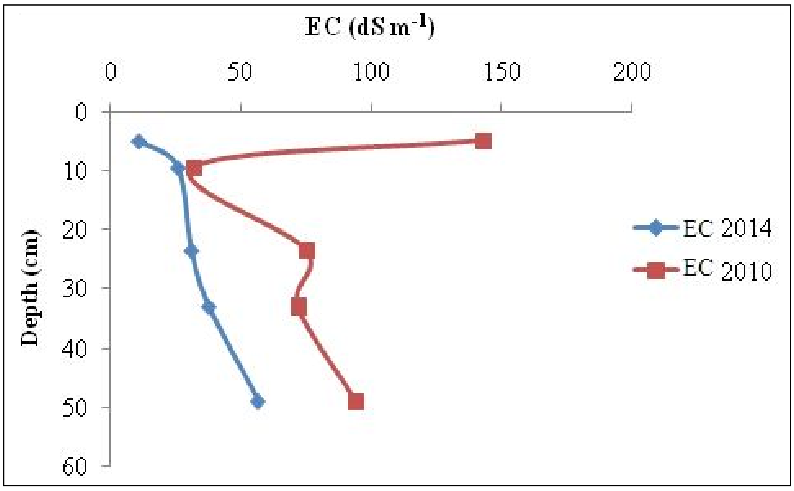

Fig 13: Profile 2 salt distribution for the two campaigns (2010 and 2014).

relatively fine texture, reduces the capillary rise of water from the salty aquifer. He accentuated the salinity of Solonchaks of the Relizane region.

However, the chemical composition of the soil solution is similar to the two campaigns, for the cations a classification order of Na^+> Ca^{++}> Mg^{++}>K^+ type and for the chloride-dominated anions (Cl^-> SO_4^{--}> HCO_3^-). This Mg^{++} is well established for its profiles 1 and 2 of the 2010 campaign, since the results come from the same report as Hadj Miloud (2010). Hadj Miloud (2019) and Hadj-Miloud (2023).

The saline profile is of the convex type for profile 3 (companion 2010 and 2014). The accumulation of salts at the level of the middle part is due to leaching of salts from the surface horizon.

Table 8: Correlations between variables and factors.

Variables	F1	F2	F3	F4	F5
EC	0.99*	-0.03	0.04	-0.05	-0.09
Na^+	0.96*	0.13	-0.10	0.06	-0.12
K^+	0.53*	-0.65	-0.32	-0.31	0.3
Ca^{++}	0.26	0.79*	0.39	-0.36	0.18
Mg^{++}	0.96	-0.20	0.05	0.00	-0.09
Cl^-	0.98*	0.08	0.00	-0.11	-0.16
HCO3-	0.09	-0.67	0.73	0.07	0.03
SO4--	0.79*	0.28	0.00	0.45	0.31

*significant at threshold α=0.05.

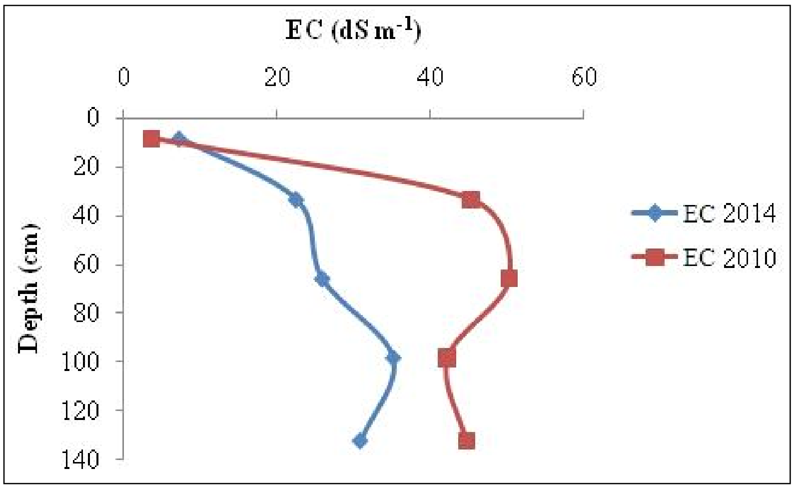

Fig 14: Profile 3 salt distribution for the two campaigns (2010 and 2014).

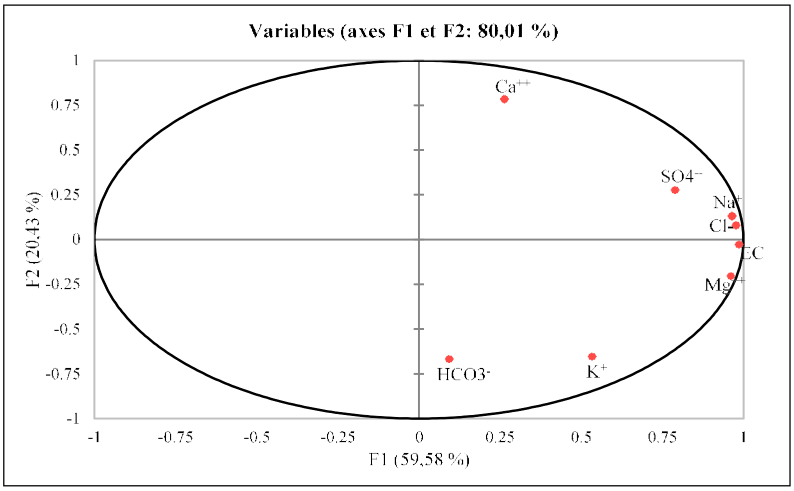

Fig 15: Principal component analysis (companion 2010).

The study of the temporal evolution of salinity showed that the majority of horizons underwent desalination between 2010 and 2014 campaign. This desalination occurred at a speed between 3.67 and 10.74 dS m^{-1} per year. This would be due to a partial leaching of salts from the surface horizons during the rainy period as shown by Servant (1975). The maximum salinity is observed at the level of middle part of profiles 1 and 3. As a result, the saline profile is of the convex type, for profile 2 the salts have accumulated in the lower part of the profile and consequently the profile saline is descending type.

Furthermore, the difference in the variation of salinization rate between the profiles is controlled by the grain size, the morphology (shrinkage cracks) and the presence or absence of a shallow and highly mineralized groundwater table (Hadj-Miloud, 2019).

Principal component analysis (PCA) showed that the chemical elements of the soil solution that had the most influence on the variability of salinity were Na^+, Mg^{++}, Cl^- and SO4--. We can explain the results of this analysis by the fact that Na^+ does not enter into the phenomenon of mineral precipitation at very high EC values (Droubi *et al*., 1980). The evolution of magnesium can be controlled by the precipitation of magnesite. In addition, the results obtained are important for the evaluation of agricultural land (Hadj-Miloud, 2022).

CONCLUSION

The main results obtained show that the three profiles presented are mainly characterized by very high salinity levels [$3.5 < EC$ (dS m^{-1}) < 143]. High sodium concentrations in the soil solution have a direct effect on high ESP values ($8.1 <$ ESP (%) < 36.6). Only the surface horizon of profile 3 which is weakly saline (EC = 3.65 dS m^{-1}) and non-sodium (ESP = 12.2%) (Hadj-Miloud *et al*., 2022).

The extreme salinity value for profile 2 (companion 2010) is visible at the level of the surface horizon (143 dS m^{-1}), the distribution of salts for companion 2014 is of convex type for profile 1 and 3. On the other hand, the salinity gradient is descending for profile 2.

The cationic and anionic composition of the soil solution is strongly dominated by sodium and chlorides for all the profiles. This explains the dominance of the chloride-sodium chemical facies.

Finally, the study of the water balance at ground level can further explain the dynamics of salts in the soil.

Conflict of interest: None.

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