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Research Article

Correlation between electrical conductivity in saturated paste extracts and different diluted extracts (1/2.5, 1/5) of coarse-textured soils

Dahman Bakhti[1*], Mabrouka Oustani[1], Mohamed Taher Halilat[1], Hafidh Zemour[2], Amar Khadoumi[3], Fathi Abdellatif Belhouadjeb[4]

[1]Bioressources sahariennes, Université Kasdi Merbah, Ouargla, Algérie
[2]Faculty of Natural and Life Sciences, Ibn Khaldoun University, BP 14000, Tiaret; Algeria
[3]Institut de Technologie Moyen Agricole Spécialisé, Djelfa 17000, Algérie
[4]Centre de Recherche en Agropastoralisme (CRApast), Djelfa 17000, Algérie

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***Corresponding author:**

E-mail:
zemourhafidh@gmail.com
bakhti.dahman@univ-ouargla.dz

Abstract

Soil salinity poses a significant challenge to agricultural productivity, necessitating precise measurement methods. Rather than relying on complex determinations like saturated paste extracts (ECe), a practical alternative involves assessing soil salinity through the Electrical Conductivity (EC) of soil-water extracts. This simplified yet reliable method is crucial for understanding the impact of soil salinity on agricultural yields. To improve accuracy in representing soluble salts relevant to plant growth, the conversion of EC from soil water extracts to ECe becomes pivotal.In an experimental study, a clear relationship was sought between the Electrical Conductivity (EC) of saturated paste extracts (ECe) and the ratios found in soil-water extracts (1/2.5 and 1/5). Fifty samples of coarse-textured soil were collected from the Djamâa palm grove in Sidi Yahia village, located in the Oued Righ region within the Djamaa Zone. The analysis of the collected data revealed compelling findings, indicating a robust and statistically significant correlation between values obtained from ECe and those derived from EC1/2.5 and EC1/5 (correlation coefficient of $R = 0.93$ and 0.91, at a significance level of $P = 0.05$). These results highlight the promising potential of accurately estimating ECe in coarse-textured soils by employing EC1/2.5 and EC1/5, paving the way for streamlining assessment methodologies for soil salinity. This study not only elucidates the correlation between conductivity measures but also proposes a practical means to estimate soil salinity more efficiently. The findings contribute to informed decision-making in agricultural practices within the Northern Sahara's Djamâa palm grove and similar regions, offering valuable insights for sustainable soil management.

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1. Introduction

Worldwide, soil salinity poses a significant threat to land productivity, with forecasts indicating that by 2050, fifty percent of all arable land will be affected by salinity (Butcher et al., 2016). Moreover, it leads to soil sterilization, resulting in their degradation (Tassano et al., 2020). One of the primary limiting factors in food production is soil salinity, especially in arid and semi-arid regions, as most crops are sensitive to increased salt concentrations in the soil solution (Libutti et al., 2018). Additionally, the accumulation of soil salinity is greatly influenced by certain agricultural practices such as fertilization, poor quality of irrigation water, absence or inefficiency of drainage networks or infiltrations (Oustani et al., 2023; Shama et al., 2016).

Currently, these issues are intensifying due to the expansion of irrigated areas in arid and semi-arid zones. Consequently, it is crucial to monitor and evaluate soil salinity to rationally manage degraded soils and ensure sustainable food production. In Algeria, according to numerous studies conducted on salinity in arid and semi-arid regions (Yahiaoui et al., 2015; Oustani et al., 2015; Abdennour et al., 2020 ; Benslama et al., 2020), all studies show an increasing trend in soil salinity, affecting their physical, chemical, and biological quality.

The measurement of electrical conductivity of saturated paste extracts (ECe) from soil is used to estimate soil salinity (Diagnoses and improvement of saline and alkali soils, 1954). Moreover, it's considered the best indicator of plant response to salinity and is recommended as a reference method for soil salinity assessment (Herrero & Pérez-Coveta, 2005). Unfortunately, saturated paste extracts are difficult, time-consuming, and require expertise to determine the appropriate saturation point (Kargas et al., 2022; Hossain et al., 2020).

Because of these reasons, several researchers have proposed that electrical conductivity could be more easily determined in extracts with different soil-to-water mass ratios, such as 1/1, 1/2, 1/2.5, and 1/5, rather than measuring EC. The most common soil-to-water mass ratios are the diluted extracts (1/1 and 1/5). In Australia and China, the 1/5 ratio is generally used to assess soil salinity (Rayment & Lyons, 2011; Wang et al., 2011), while the United States often uses the 1/1 ratio (He et al., 2012).

Furthermore, soil-water extractions are considered less linked to the natural soil conditions compared to the SP extraction method. Ion concentrations and electrical conductivities of various soil-water extracts are generally lower than those obtained by the ECe protocol due to the higher dilution of soil solutions (Kargas et al., 2018). Indeed, the impact of water on the dissolution of less soluble salts like gypsum and calcite is the primary drawback of using soil-water extracts (Rhoades et al., 1999).

However, the conversion factor (CF) of EC values from different ratios to ECe in one region cannot be used to determine another with different soil characteristics, as significant errors will occur in predicting ECe (Kargas et al., 2022). Indeed, the relationship between ECe and EC of different soil-water extracts is influenced by soil texture and the presence of salts and gypsum in the soil (United States Salinity Laboratory, 1954). Additionally, differences observed between various models are likely caused by time and equilibration method (He et al., 2013).

It has been proven that in coarse-textured soils, the conversion factor has a higher value than in fine-textured soils (Sonmez et al. 2008; Kargas et al., 2018). Thus, a better understanding of the transferability of these models would provide managers with more information about the accuracy of ECe values derived from non-local EC conversion models (Khorsandi & Yazdi, 2011; Aboukila & Norton, 2017).

In Algeria, soil salinity is generally assessed using the EC1/2.5 and EC1/5 methods. However, there isn't a proposed or utilized equation to relate ECe to EC1/2.5 or EC1/5 for coarse-textured soils. The aim of this study is to investigate the relationship between ECe=f(EC1/2.5) and ECe=f(EC1/5) of soil samples collected from the palm grove of Sidi Yahia, located in the heart of the Oued Righ region, 500 km southeast of Algeria, in the Lower Sahara basin.

2. Materials and methods

2.1 Study area

The palm grove of the village Sidi Yahia, established in 1986, is located approximately 2 km west of the daïra of Djamâa in the Méghaier province, Southeast Algeria, stemming from the latest administrative division in 2019 officially recognized in 2021. It lies between latitudes 33.51.58.53° North and longitudes 5.961646° East, at an altitude of 45 meters in the central area, as per the geomorphology of the Oued-Righ valley (Figure 1).

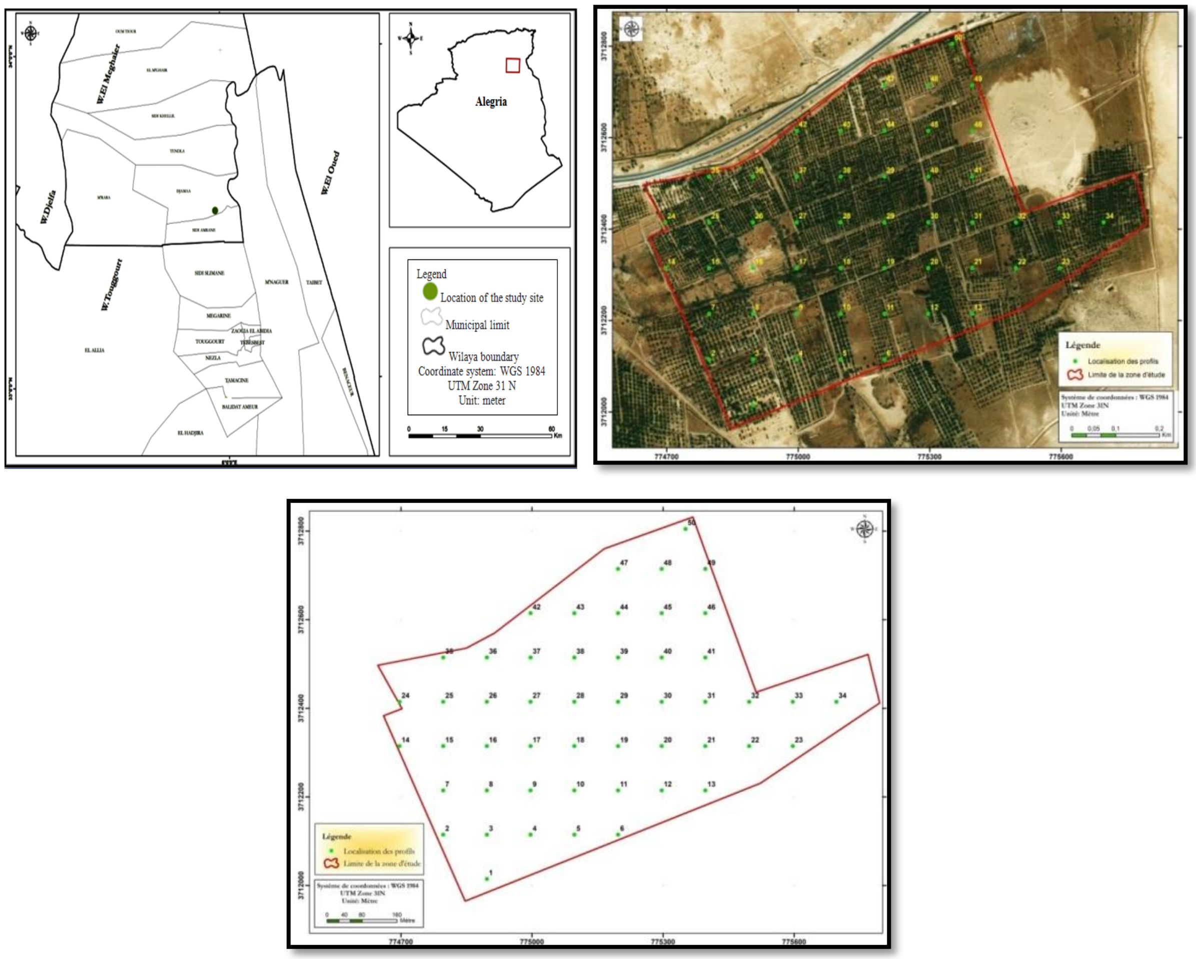

Figure 1. Localization of the study area in Sidi Yahia (Algeria) and positions of soil samples in the orchard.

The experimental zone covers approximately 50 hectares, divided into plots of around 1 hectare, with planting spacing's of 10 meters, as practiced by local farmers. The OuedRigh region experiences an extremely dry desert climate characterized by mild winters, hot and dry summers, and low, irregular precipitation. The average annual precipitation in the study area was around 5.06 mm, with average annual temperatures of 22.35°C and maximum temperatures of 34.44°C between 1975 and 2020. The Thorn Thwaite method measured the actual evaporation potential (ETR) at 60.79 mm and the potential evapotranspiration (ETP) at 1,188.36 mm (Mehibel & Dorbi, 2022).

2.2 Geological and hydrogeological context

Outcrops at the edges of the Lower Sahara are primarily composed of Mesozoic and Cenozoic formations. The central basin is occupied by continental deposits dating from the late Tertiary and Quaternary periods. Two significant hydrogeological units from the Post-Paleozoic era are present in the geological series: the Continental Intercalaire and the Terminal Complex (Figure 2) (Belksier et al., 2014).

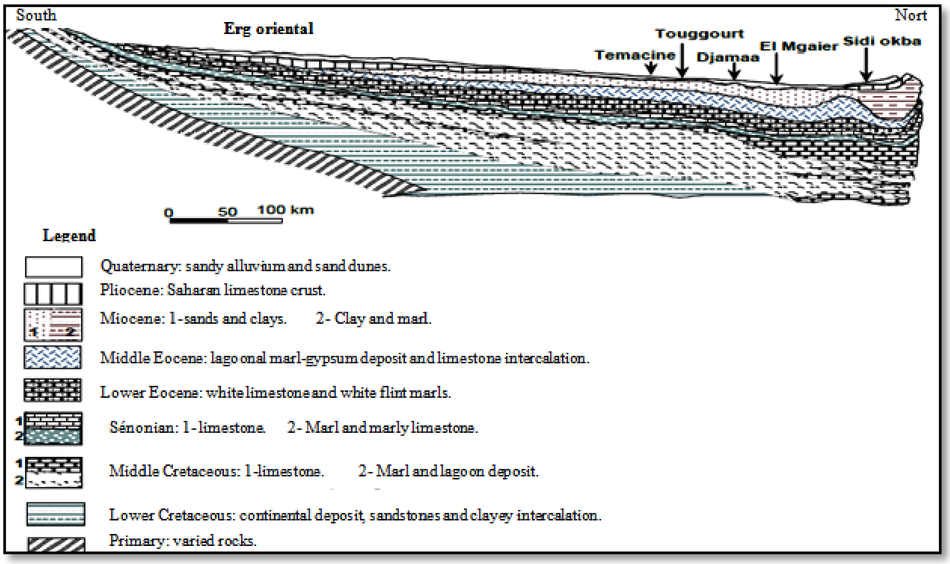

Figure 2. North-South geological cross-section passing through the Saharan Secondary Basin and the OuedRigh Basin. Source: Belksier et al., (2014).

The two main aquifer systems in the region are the Terminal Complex (CT) and the Continental Intercalaire (CI). Both systems are overlain by the water table, present throughout the oases. The Continental Intercalaire aquifer is artesian, with a total capacity of over 30,000 billion cubic meters. It houses the largest amount of groundwater in the Algerian Sahara. The free aquifer of the terminal complex overlies this aquifer (Figure 3) (Chaib et al., 2013).

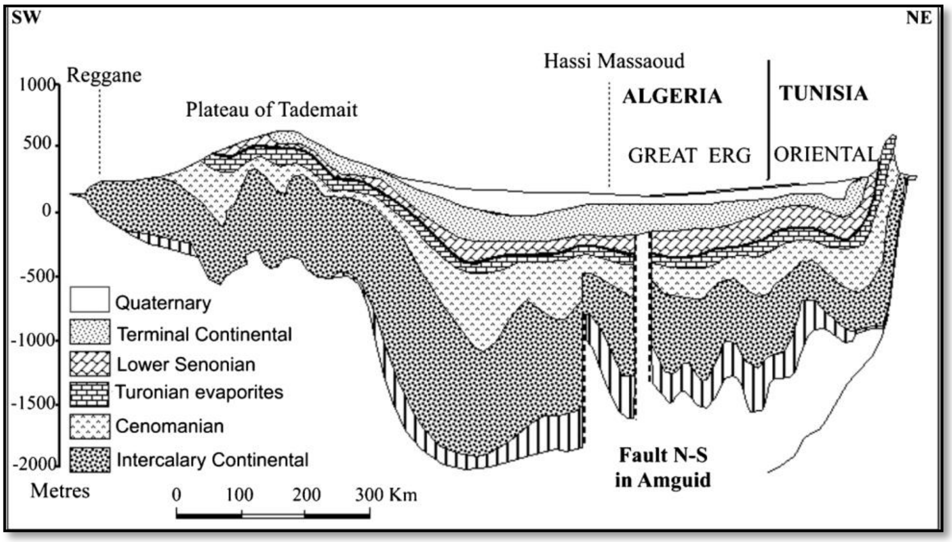

Figure 3. Synthetic hydrogeological cross-section of the Northern Sahara. Source: Chaib et al., (2013)

2.3 Soil sampling and analysis

In March 2023, soil samples were systematically collected, and spatial data were generated using a Geographic Information System (Arc-GIS) covering all study sites. We were able to place 50 observation points, one per plot, using this sampling plan. Soil samples were taken at a depth of 20 cm using an agricultural auger, and precise positions in latitude and longitude of the ground points were determined using the UTM Geo Map application. The samples were dried at 105°C overnight in an oven. Subsequently, they were ground and sieved using a 2 mm sieve to obtain fine soil. They were stored in plastic bags for further analysis, including electrical conductivity (EC), pH, organic matter (OM), and total limestone content.

2.4 Methods and soil extraction measures

2.4.1 Saturated paste extraction method

The standard method (Diagnoses and improvement of saline and alkali soils, 1954) was employed to determine saturated paste extracts of soil by adding distilled water to approximately 200 g of soil and stirring until complete saturation. When a homogeneous saturated paste shines, slightly flows when turned, slides freely and cleanly on a smooth spatula, forms jars after making a furrow, and meets a state of free water precipitation, saturation is considered reproducible enough for the SP (Corwin & Yemoto, 2020).

The pastes were left for 24 hours to reach equilibrium. Extracts from each paste were obtained by vacuum filtration using filter paper placed in a Büchner funnel over a vacuum flask. The extracts were then collected in 50 ml polyethylene bottles, and readings of EC and pH were measured at 25°C using a Jenway 4510 conductimeter and a Mettler Toledo pH meter**.**

Table 1. Salinity scale based on EC of saturated paste extract

Saturated paste electrical conductivity	Soil class
EC ≤ 2 dS/m	Not saline
2 dS/m < EC ≤ 4 dS/m	Slightly saline
4 dS/m < EC ≤ 8 dS/m	Saline
8 dS/m < EC ≤ 16 dS/m	Highly saline
EC > 16 dS/m	Extremely saline

Source: Diagnoses and improvement of saline and alkali soils (1954)

2.4.2 Soil-water extraction methods 1/2.5 and 1/5

Soil-water suspensions were prepared by placing a weight (X g) of each sample in a 100 ml polyethylene bottle and adding different volumes of distilled water according to the soil/water ratios of 1/2.5 and 1/5 (Table 2). They were kept at room temperature for 23 hours and then shaken on a different shaker (132 rpm-1) for 1 hour (Soil Survey Staff, 2011). After agitation, the soil solutions were transferred to 50 ml polyethylene bottles and centrifuged in a centrifuge at 4000 rpm for 5 minutes. EC and pH readings were measured at 25°C using a Cond 7110 benchtop conduct meter and a Mettler Toledo-type pH meter."

Table 2. Diluted extract ratios (soil/water)

Soil/water	Soil (g)	Water (cm^3)
1/2,5	10	25
1/5	10	50

NB: 1 cm^3 = 1 ml

Table 3. Salinity class based on electrical conductivity of aqueous extract at 25°C (1/5)

EC ds/m à 25°C	Salinity Levels
EC ≤ 0,6	Non-saline soil
0,6 < EC ≤ 1	Slightly saline soil
1 < EC ≤ 2	Moderately saline soil
2 < EC ≤ 4	Highly saline soil
EC > 4	Extremely saline soil"

Source: Durand (1983)

2.4.3 Soil property determination methods

To determine soil texture, only 8 representative soil samples were randomly selected to ascertain soil texture, total limestone, and organic matter (OM). The Bernard Calcimeter method was used to estimate the equivalent percentage of $CaCO_3$ by measuring the CO_2 emitted upon the addition of HCl. The organic matter (OM) content was determined by organic carbon analysis (Anne's Method). Carbon is oxidized by potassium bichromate in a sulfuric acid medium. A solution of MOHR salts is used to titrate the excess potassium bichromate, in the presence of diphenylamine which changes color from dark blue to green.

Table 4. Standards for assessing total soil limestone

Total $CaCO_3$ %	Normes
< 1	Non-calcareous
01-05	Slightly calcareous
05-25	Moderately calcareous
25 - 50	Strongly calcareous
50 - 80	Very strongly calcareous
Plus de 80	Excessively calcareous"

Table 5. Organic matter % Scale

Organic matter %	Class Name
0,5 - 1	Very Low in organic matter
01-02	Low in organic matter
02-03	Moderate to Low in organic matter
03-05	High in organic matter
> 5	Very High in organic matter

2.4.4 Water sampling and analysis

The quality and quantity of water used for irrigation determine the sustainability of agricultural yield in palm groves. The soils in our study area are irrigated using water from the terminal complex. To assess the physicochemical properties of water, irrigation and drainage water samples were collected in March 2023 and stored immediately at a temperature below 4°C. Analyses were conducted following the protocols outlined in (Rodier, 2009).

2.5 Statistical analyses

A descriptive statistical analysis of the obtained data was performed to calculate the mean, minimum, maximum, standard deviation, median, standard error, sample variance kurtosis, skewness, and range for each parameter. Regression analysis was also conducted for the electrical conductivity of soil saturated paste extracts in relation to those obtained from the 1/2.5 and 1/5 ratios with and without intercepts. In this study, the generated regression relationships were evaluated using regression slopes (r).

3 Results and discussion

3.1 Soil properties

The studied soil exhibits a sand content of 70.63 ±2.21%, silt content of 22.57 ±2.4%, and clay content of 6.8 ±2.14% (Table 6). According to the World Reference Base for Soil Resources (World Reference Base for Soil Resources, 2015), the soil in the study area has a sandy loam texture.

Table 6. Descriptive statistics of the physical and chemical properties of soil in the Sidi Yahia palm grove

	Valid N	Mean	Median	Mini	Max	Variance	Std.Dev.	Coef.Var.	Skewness	Kurtosis
Clay %	8	6.80	5.70	5.03	10.07	4.58	2.14	31.44	0.66	-1.73
Silt %	8	22.57	22.65	18.59	26.640	5.77	2.40	10.64	-0.02	0.84
Sand %	8	70.63	70.72	68.14	74.61	4.88	2.21	3.13	0.59	0.02
Organic Matter %	8	0.54	0.51	0.41	0.76	0.014	0.12	21.86	1.06	0.76
Total Limestone %"	8	3.68	3.75	3.40	3.80	0.03	0.16	4.30	-0.90	-0.69

The organic matter content in the soil samples ranged from 0.41 ± 0.12 to 0.76 ± 0.12%, with a mean close to 0.54 ± 0.12%. According to Morand (2001), the study area falls within the class of soils with very low OM, not exceeding 1% (Table 5). As per the evaluation standards by Baize (2018) (Table 4), the study area belongs to the class of soils with low limestone content, ranging from 3.4 ± 0.16 to 3.8 ± 0.16% and having a mean close to 3.68 ± 0.16%."

3.2 Irrigation water quality

The physicochemical characteristics of irrigation and drainage waters are presented in Table 7 and Table 8. The pH of both waters was close to neutral. The EC value of the drainage water is two and a half times higher than that of the irrigation water. The increase can be attributed to leaching, which enriches the water with soil electrolytes**.**

Table 7. Physical and chemical properties of Sidi Yahia irrigation and drainage water

	pH	EC (dS/m)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	Na^{+} (meq/L)
Irrigation	7.23	10.4	21.08	20.55	25.29
Drainage	7.44	26.2	42.53	76.95	94.93

Table 8. Physical and chemical properties of Sidi Yahia irrigation and drainage water

	K^{+} (meq/L)	HCO_3^{-} (meq/L)	Cl^{-} (meq/L)	SO_4^{2-} (meq/L)	S.A.R. (meq/L)
Irrigation	0.72	2.68	51	27.12	5.54
Drainage	1.96	9.45	182.6	33.79	12.28

The Piper diagram was employed to determine the water's chemical facies. To assess the risk of soil sodification and salinization, the Riverside diagram (1954) was utilized. Wilcox (1948) proposed a method to evaluate irrigation waters using sodium percentage and electrical conductivity. The sodium percentage can be calculated using the following formula:

$$"\boldsymbol{Na^+} = \frac{(\boldsymbol{Na^+} + \boldsymbol{K^+})}{(\boldsymbol{Ca^{+2}} + \boldsymbol{Mg^{+2}} + \boldsymbol{Na^+} + \boldsymbol{K^+})} \times \mathbf{100}$$

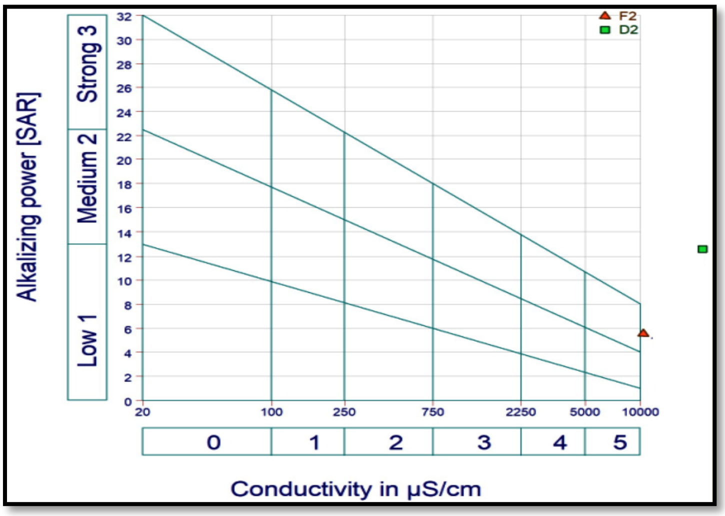

Figure 4. Evaluation of the quality of irrigation waters (F2) and drainage waters (D2) based on the Wilcox diagram

The Wilcox diagram indicates a single poor quality class for both types of waters**.**

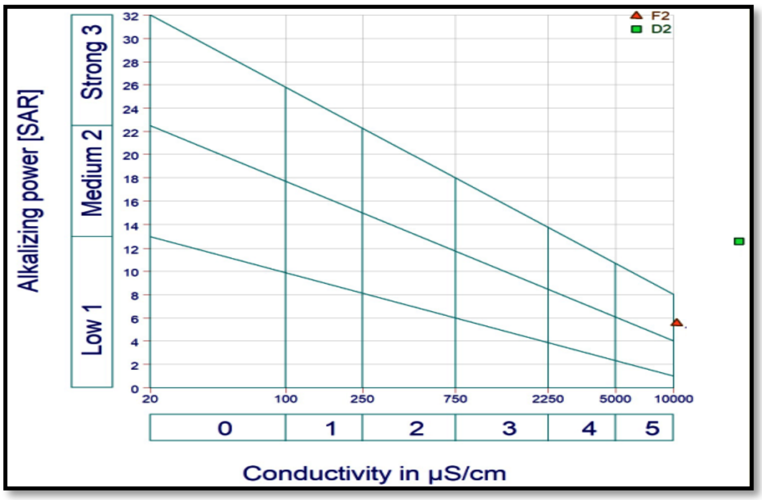

Figure 5. Classification of irrigation waters (F2) and drainage waters (D2) on the Riverside diagram

The Riverside diagram (Figure 5) illustrates the combined effect of EC and SAR. The irrigation water samples belong to class C5S3, indicating a high risk of salinity and a significant risk of alkalinity, as depicted on this diagram. Furthermore, the drainage water samples fall into class C5S4, indicating a very high risk of salinity and a significant risk of alkalinity. The irrigation suitability diagrams show results confirming that the mineral load will harm the soil and plants irrigated with these waters. As a conclusion, it is strongly recommended to avoid using these waters for irrigation purposes**.**

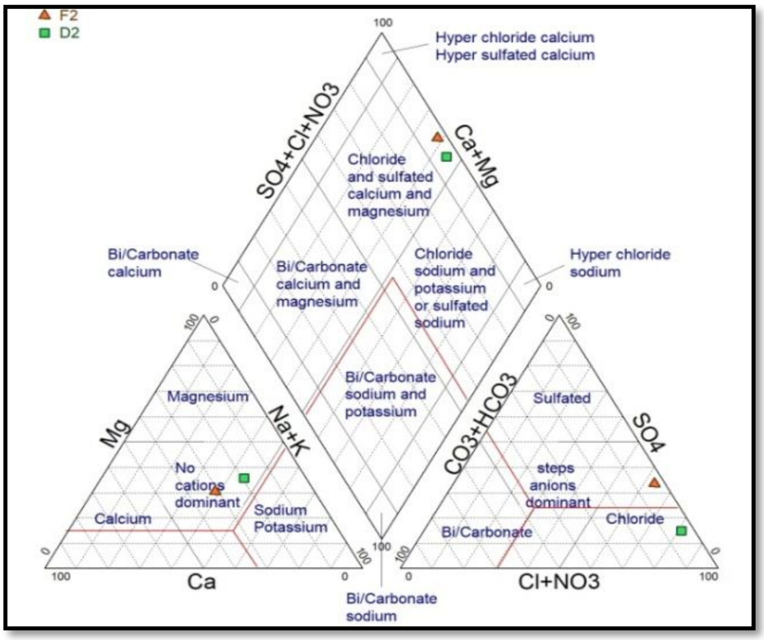

Figure 6. Piper Diagram applied to irrigation waters (F2) and drainage waters (F2)

According to the results of the Piper diagram (Figure 6), both samples, F2 and D2, exhibit a primary chemical facies of sodium chloride, along with a hidden chemical facies of Sulfate-Calcium and Sulfate-Magnesium, respectively.

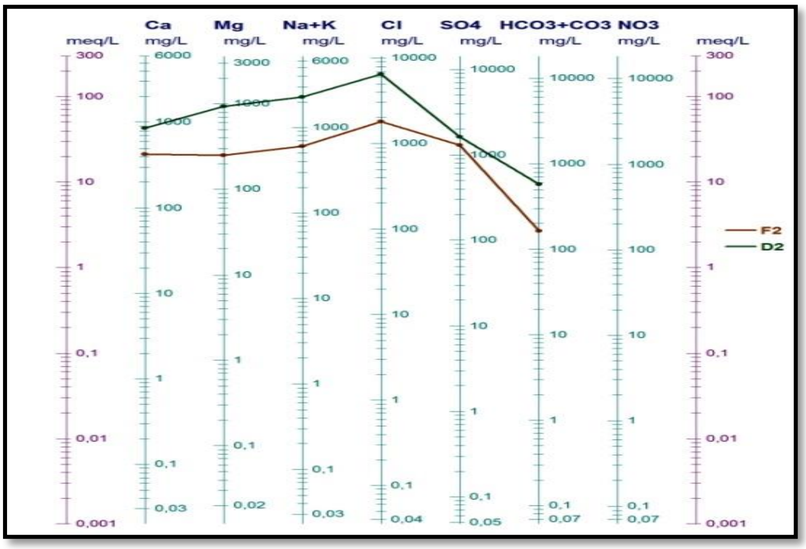

Figure 7. Schöeller-Berkaloff diagram applied to irrigation waters (F2) and drainage waters (F2).

According to the Schöeller-Berkaloff diagram (Figure 7), the dominant ions in the irrigation and drainage waters are chlorides for anions and sodium for cations. Based on the results of hydrochemical analysis of the waters, there is a very high mineral content in both presented samples. The ionic formula for the waters is as follows:
F2: $Na^+ > Ca^{2+} > Mg^{2+} > K^+ : Cl^- > SO_4^{2-} > HCO_3^-$.
D2: $Na^+ > Mg^{2+} > Ca^{2+} > K^+ : Cl^- > SO_4^{2-} > HCO_3^-$.

3.3 Soil salinity

Soil salinity generally increases proportionally with the salt concentration in irrigation water. The soil's electrical conductivity can be two to six times higher than the salt concentration in the irrigation water (Pérez-Sirvent et al., 2003). However, since all soils are irrigated with the same water, other factors also affect salinity, such as agricultural management and environmental conditions. Among these factors is the poor maintenance of the drainage network, leading to wastewater stagnation and sanitation issues in the Oued Righ region (Belkesier, et al., 2018).

Additionally, the inefficiency of the drainage system due to vegetation growth, such as reeds, or water seepage back into plots observed during field surveys. Moreover, the excessive use of water has saturated the soils in the Oued-Righ valley with both water and salts (Kadri et al. 2022), leading to the presence of salt crusts on the soil surface (Figure 8 and Figure 9). These factors could explain the high EC values observed in the study area.

Figure 8. Salinity in the palm grove

Figure 9. Presence of salt crusts on the surface of the ground

Table 9 showcases the descriptive statistics of the electrical conductivity in soil samples. The electrical conductivity of the soil samples ranged from 8.11 to 170.4 mS/cm for the saturated paste extracts (ECe), from 3.24 to 40.60 mS/cm for the 1/2.5 soil-water extracts, and from 2.47 to 25.01 mS/cm for the 1/5 soil-water extracts. These results indicate a broad range of salinity levels used to compare the SP method with the EC1/1 and EC1/5 methods.

Our findings align with previous research, demonstrating that the electrical conductivity of diluted extracts is lower than that of saturated paste extracts (Diagnoses and improvement of saline and alkali soils, 1954; Ozcan et al., 2006; Sonmez et al., 2008; Aboukila & Norton, 2017; Kargas et al., 2018). The saturated paste extracts exhibited an average ECe of nearly 83.18 mS/cm, approximately 4.71 times higher than the 1/2.5 soil-water extracts and roughly 7.44 times higher than the 1/5 soil-water extracts. These results closely resemble those of Sonmez et al. (2008) and

Aboukila & Abdelaty (2017), who found that the average ECe was around four times and eight times higher than EC1/2.5 and EC1/5, respectively.

Table 9. Descriptive statistics of electrical conductivity for saturated paste extracts (ECe) and two soil-water eExtract ratios (EC1/2.5 and EC1/5) for studied soils in SidiYahia

	Valid N	Mean	Median	Mini	Max	Variance	Std.Dev.	Coef.Var.	Skewness	Std.Err - Kurtosis
Ece (mS/cm)	50	83.18	88.55	8.11	170.40	1457.67	38.18	45.90	0.09	0.66
EC1/2,5 (mS/cm)	50	17.66	17.93	3.24	40.60	72.79	8.53	48.32	0.53	0.66
EC1/5 (mS/cm)	50	11.18	11.55	2.47	25.01	26.11	5.11	45.70	0.51	0.66

The measurements of the EC in the studied soil samples showed a significant difference between the EC of extracts (1/2.5, 1/5) and the EC of saturated paste extracts. The EC of soil extracts tends to decrease with an increase in the soil-to-water ratio, probably due to dilution effects, as suggested by Diagnoses and improvement of saline and alkali soils (1954) and Sonmez et al., (2008). The 50 soil samples were classified into two classes for SP and four classes for diluted ratios: 0–2, 2–4, 4–8, 8–16, and >16 mS/m. Table 10 contains the values of each class along with the corresponding percentages. In comparison, approximately 96% of soil samples had an ECe greater than 16 mS/cm, 56% had an EC1/2.5 greater than 16 mS/cm, and 16% had an EC1/5 greater than 16. These results demonstrate the use of multiple EC values in comparing the SP method with EC1/2.5 and EC1/5 methods.

Table 10. Electrical conductivity of saturated paste extracts (ece) and two soil-water extract ratios (EC1/2.5 and EC1/5) for studied soils

Range of EC(mS/cm)	ECe		$EC_{1/2,5}$		$EC_{1/5}$	
	No of Samples	% of Samples	No of Samples	% of Samples	No of Samples	% of Samples
02-04	0	0	2	4	4	8
04-06	0	0	4	8	10	20
06-16	2	4	16	32	28	56
> 16	48	96	28	56	8	16

3.4 Relationship between ECe and EC1/2.5, EC1/5

To do this, for each dilution pair, we found the equation of its linear regression and its correlation coefficient r with its statistical significance threshold $p < 0.05$ (Table 11). The graphs of the three pairs of data are represented in Figures 10, 11, and 12. It has been demonstrated that there is a strong correlation between ECe and the values of EC1/2.5 and EC1/5 ($R = 0.93$ and 0.91, $P = 0.05$), suggesting that it is possible to assess ECe in coarse-textured soils from EC1/2.5 and EC1/5. It is interesting to note that the relationship between EC1/2.5 and EC1/5 (Figure 12) of the diluted extracts is very strong and highly significant ($r = 0.98$, $p < 0.05$).

The slopes for the 1/2.5 and 1/5 extracts in our study were 4.15 and 6.77, which is close to the slopes of 3.73 and 7.46 reported by Aboukila & Abdelaty (2017). Regarding the relationship between ECe and EC1/2.5, the slope of 4.15 is comparable to the slope of 4.34 reported by Sonmez et al. (2008). Furthermore, the slope of 6.77 derived from the ECe and EC1/5 relationship is significantly different from the slope value of Sonmez et al. (2008); Monteleone et al. (2016), whose slope values are 8.22 and 9.63, respectively.

The clay content of the soil samples, the type of clay (Sonmez et al., 2008), the types of salts present (Ismayilov et al., 2021 ; Isdory et al., 2021), the gypsum content (Khorsandi & Yazdi, 2007 Khorsandi & Yazdi ,2011), equilibration time, and equilibration method (He et al., 2013),as well as the ECe range of the soil samples used to create a conversion equation (Aboukila & Norton, 2017), may contribute to the differences in regression equations reported by different researchers. Correlations Sidi yahia in (Table 11) marked correlations are significant at $p < 0.05000$ N=50 (Casewise deletion of missing data)"

Table 11. Statistical parameters of the three dilution pairs with soil-water ratio for the studied soils with statistical significance threshold $p < 0.05$

	Means	Std.Dev.	EC_e (mS/cm)	$EC_{1/2,5}$ (mS/cm)	$EC_{1/5}$ (mS/cm)
EC_e (mS/cm)	83.17880	38.17939	1.000000	0.927280	0.906442
$EC_{1/2,5}$ (mS/cm)	17.65680	8.53141	0.927280	1.000000	0.981223
$EC_{1/5}$ (mS/cm)	11.17980	5.10950	0.906442	0.981223	1.000000

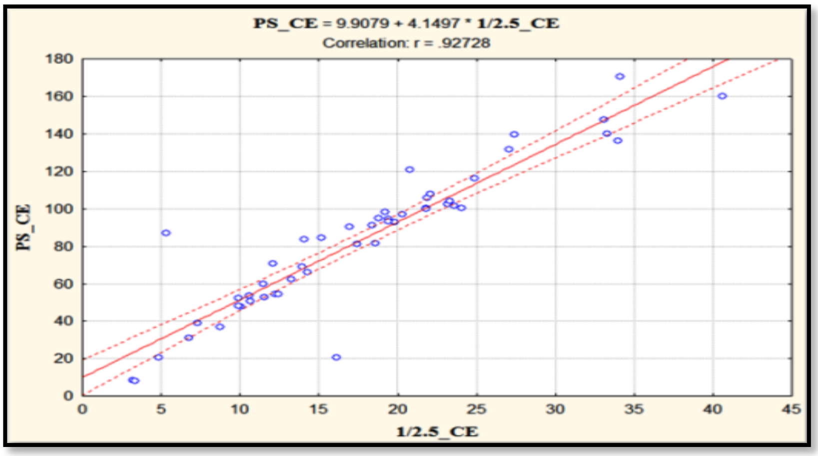

Figure 10. Correlation between the electrical conductivity of saturated paste and the electrical conductivity of diluted extracts EC1/2.5

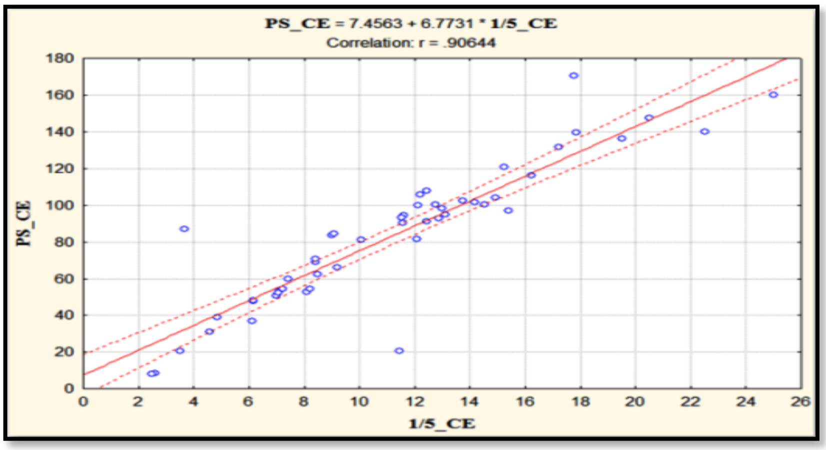

Figure 11. Correlation between the electrical conductivity of saturated paste and the electrical conductivity of diluted extracts EC1/5

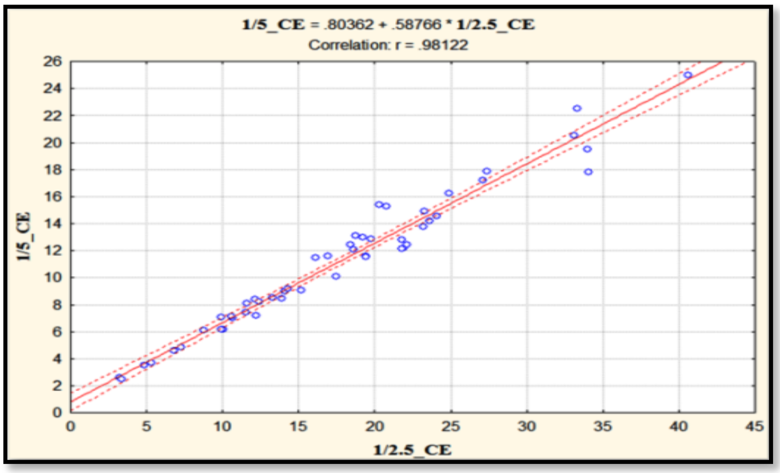

Figure 12. Correlation between the electrical conductivity of diluted extracts EC1/2.5 and the electrical conductivity of diluted extracts EC1/5

Table 12 presents correlation equations proposed by various researchers to convert soil-water extracts at different ratios (EC1/x) into saturated paste equivalents (ECe). The studies include those conducted by Diagnoses and Improvement of Saline and Alkali Soils (1954), Zhang et al. (2005), Ozcan et al. (2006), Sonmez et al. (2008), Khorsandi and Yazdi (2011), Monteleone et al. (2016), Klaustermeier et al. (2016), Aboukila and Norton (2017), Aboukila and Abdelaty (2017), and John et al. (2021). The regression equations provided by these researchers, both with and without intercepts, are presented along with their respective R-squared values. The range of ECe values covered by each equation is specified, and units for electrical conductivity (EC) are in dS m-1. Additionally, specific notes regarding soil textures, the presence of gypsum, and data availability are included for clarification. The study at the end of the table introduces its own correlation equations, specifying the coefficients and their associated R-squared values for coarse-textured soils.

Table 12. Correlation equations to convert soil-water extracts at different ratios (EC1/x) into saturated paste equivalents (ECe) proposed by various researchers

Study	Regression equation				ECe Range a
	With intercept	R2	Without intercept	R2	
Diagnoses and improvement of saline and alkali soils (1954)			ECe =3 EC1/1 b	0.96	N/Ag
Zhang et al. (2005)	ECe =1.79 EC1/1 + 1.46 b	0.85	ECe =1.85 EC1/1 b	0.85	0.16-108
Ozcan et al. (2006)	ECe =1.93 EC1/1 – 0.57	0.96			N/A
	ECe =3.30 EC1/2.5 – 0.20	0.95			N/A
	ECe =5.97 EC1/5 – 1.17	0.94			N/A

Continued Table 12…

Study	Regression equation				ECe Range a
	With intercept	R2	Without intercept	R2	
Sonmez et al. (2008)	ECe =2.72 EC1/1 – 1.27 c	0.99	ECe =2.42 EC1/1 c	0.98	0.22-17.7
	ECe =4.34 EC1/2.5 + 0.17 c	0.99	ECe =4.41 EC1/2.5 c	0.99	0.22-17.7
	ECe =8.22 EC1/5 – 0.33 c	0.98	ECe =7.98 EC1/5 c	0.98	0.22-17.7
Khorsandi and Yazdi (2011)	ECe = 5.43 EC1/5 + 0.43 d	0.96	ECe =5.48 EC1/5 d	0.96	0.63-91.7
	ECe = 5.75 EC1/5 – 4.45 e	0.97	ECe =5.37 EC1/5 e	0.96	0.54-126
Monteleone et al. (2016)			ECe =9.63EC1/2.5 b	0.99	0.15-62.9
Klaustermeier et al. (2016)	ECe = 10[1.256 (log EC1/5) + 0.766] b	0.97			0.41-126
Aboukila and Norton (2017)	ECe =3.05 EC1/2.5 + 0.41 f	0.93	ECe =3.34 EC1/2.5 f	0.92	0.62-10.3
	ECe =5.04 EC1/5 + 0.37 f	0.93	ECe =5.49 EC1/5 f	0.92	0.62-10.3
Aboukila and Abdelaty (2017)	ECe =3.73 EC 1/2.5 + 0.79 c	0.96	ECe =4.13 EC1/2.5 c	0.94	0.29-18.3
	ECe =7.46 EC1/5 + 0.43 c	0.97	ECe =7.89 EC1/5 c	0.96	0.29-18.3
John et al. (2021)	ECe = 1.83 (EC1/1) + 0.117 f	0.97	ECe = 1.84 EC1/1 f	0.97	0.47 – 37.5
	ECe = 6.53 (EC1/5) – 0.108 f	0.93	ECe = 6.47 EC1/5 f	0.93	0.47 – 37.5
This study	ECe =4,15 * EC1/2,5 + 9,91 c	0.93		….	…
	EC_e =6,77 * $EC_{1/5}$+ 7,46 c	0.91			

a- Units of EC are in dS m-1.
b- Combined soil textures.
c- Coarse-textured soils.
d- Coarse-textured soils without gypsum.
e- Coarse-textured soils containing gypsum.
f- Fine-textured soils.
g- Data not available

Conclusion

This research uncovered a robust link between ECe and the values of EC1/2.5 and EC1/5 (R = 0.93 and 0.91, P = 0.05), underlining the significance of accurately assessing ECe in coarse-textured soils. This correlation showcases a potential for precise evaluation techniques in determining soil electrical conductivity. Furthermore, the study shed light on the prevailing soil salinity levels within the region, delineating two distinct categories: highly saline and extremely saline, characterized by electrical conductivities of saturated paste extracts ranging between 8 and 16 mS/cm and surpassing 16 mS/cm. By leveraging these correlations, not only can time and expenses be minimized, but it also enables effective monitoring and management of soil salinity in the study area. This approach maintains a high degree of accuracy and precision in measuring ECe, thereby enhancing the overall control and understanding of soil salinity dynamics.

Author's declaration

The authors affirm the absence of any conflict of interest. Additionally, all contributors to the work have made equal contributions, and the entire author team unanimously agreed to and provided consent for the final version of the work.

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