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Case Report

DIAGNOSIS OF SOIL SALINITY IN THE LOW-CHELLIF PLAIN, NORTH-WEST ALGERIA, BY JOINT MEASUREMENTS OF ELECTRICAL AND HYDRAULIC CONDUCTIVITIES

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SUMMARY

Land use in arid and semi-arid regions is a serious challenge for sustainable production, owing not only to drought and climate change but also to water availability. Irrigated perimeters in these regions are subject to secondary salinization that negatively impacts soil quality and agricultural productivity. Monitoring and diagnosing the extent of soil contamination requires a more innovative approach to optimize rehabilitation of affected areas. In the present study, diagnosing of saline soil degradation is conducted by using two key indicators: electrical conductivity of saturated paste extract (ECe) and saturated hydraulic conductivity (HCs). The results of the study reveal that the value of ECe in 85% of the Lower Chellif Plain area (north-west Algeria) is ECe < 2 dS m^{-1}, while 78% of the area is moderately permeable. These findings underscore high spatial variability in salinity distribution, indicating that the process of salinization has not yet reached a critical stage. Furthermore, it is concluded that ECe and HCs are appropriate indicators for diagnosing salinity of soil in relation to its structural and permeability characteristics.

Key words:
electrical conductivity, saline soil, saturated hydraulic conductivity, lower Chellif plain

Abbreviations:
ECe – electrical conductivity of saturated paste extract; HCs – saturated hydraulic conductivity; CV – coefficient of variation; USDA – United States Department of Agriculture; Hi – initial soil moisture; Hs – saturated soil moisture; BD – bulk density; INRAA – National Institute of Agronomic Research Algeria; INSID – National Institute of Soil, Irrigation and Drainage

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INTRODUCTION

Environmental protection issues are directly related to the theme of sustainable development. In this context, soil holds a special place in relation to other environmental compartments – water, air and living organisms, owing to its vital role in production and ecological processes (Brevik & Sauer, 2015). Serving as a carrier for water and a habitat for living organisms, soil is the main concern in sustainable agri-food production. Its physical, chemical, and biological processes must be monitored both spatially and temporally in order to prevent its premature degradation and ensure timely preservation, not only of the soil itself but also of other environmental compartments.

Soil salinity is one of the most common forms of soil degradation in arid and semi-arid regions, having detrimental effects on water resources, fauna, and flora. Although this phenomenon can occur naturally, it is frequently induced by anthropic interventions. It negatively affects crop productivity, thereby jeopardizing a country's food security.

Based on the global data covering 73% of land (i.e. land that has been mapped), the area of salt-affected soils covers 424 million ha of arable land (0-30 cm depth) and 833 million ha of subsoil (30-100 cm depth) (FAO, 2021). Another study reveals that one billion ha of land is negatively affected by salinity, including more than 20% of all irrigated arable land (Qadir et al., 2014). Increasing salinization raises concerns not only about the global food supply system but also about agricultural production systems, having significant impact on utilization of land and natural resources (Negacz et al., 2022). In arid and semi-arid regions, the trends in climate change are the main driver of salinization, as increased evaporation results in continuous accumulation of salts. In addition, wind erosion can extend saline soil areas into previously unaffected regions. In practice, salinization predominantly arises from inadequately conducted irrigation using poor quality (salt-rich) water and under inadequate drainage conditions (Ruto et al., 2018). In such circumstances, the impact of anthropogenic activities on saline soil management becomes notable.

In order to establish an early diagnosis of soil degradation, it is important to monitor and map soil salinity. In this context, remote sensing has surpassed traditional methods of assessing soil salinity, offering rapid and more comprehensive estimation techniques capable of covering large areas. Remote sensing data are obtained using various types of sensors based on visible features of soil surface or on the presence of halophytic plants (Zare-Mehrjardi et al., 2010; Allbed & Kumar, 2013). However, this limits the accuracy of salinity mapping analysis given the spatial, temporal, and vertical variability in soil profile. Furthermore, spectral reflectance, covering only the soil surface, cannot provide information on the entire soil profile (Schmugge et al., 2002; Sethi et al., 2010), as soil surface features cannot be representative of the deeper soil profile (Dewitte et al., 2012). Therefore, an approach based on ECe and HCs indicators is an accurate and rapid method for diagnosing soil degradation caused by salinization (Tamoh & Maslouhi, 2004). These two soil quality indicators (HCs and ECe) can be mapped using the ordinary kriging spatial interpolation method, which is therefore a relevant way of diagnosing soil salinity for sustainable hydro-agricultural management of irrigated areas. Using this approach, we can control the level of soil salinity by regulating irrigation, operation of the drainage system and judicious selection of crops suitable for local conditions. The aim of the present study is to show that soil salinization can be diagnosed by measuring two significant parameters: saturated paste extract electrical conductivity (ECe) and saturated hydraulic conductivity (HCs).

MATERIAL AND METHODS

Study area description

The study plot is located in the Lower Chellif Plain, covering an area of 24 hectares. This area is characterized by saline soils with clay and silty-clay textures. The Lower Chellif Plain is situated in northwestern Algeria (Fig. 1), between 0°40′ and 1°6′8″ east longitude and 34°3′12″ and 36°5′57″ north latitude. This region is marked by a harsh semi-arid climate, with hot summers, low temperatures in winter and a long dry period. The average annual rainfall and evapotranspiration are 307 and 1061 mm year^{-1}, respectively (Bradai, 2017).

The soils in this region are composed of alluvial deposits originating from neighboring watersheds, primarily comprising shales and marls from the Miocene and Pliocene, which are often rich in salts. These alluviums primarily consist of clays and silts, frequently exhibiting saline characteristics (Douaoui et al., 2006; INSID, 2008). These soils are classified as sodic solonchaks according to WRB (2006). The main water resource in the region is an underground alluvial aquifer characterized by high salinity.

This area has experienced variable dynamics in land use and crop selection, directly influenced by climatic factors, water availability and soil salinity. The predominant crops cultivated in this zone are mainly cereals. During the period of our experiment, the land remained fallow covered by different types of natural vegetation including *Atriplex halimus*, *Salsola sp*. and *Sueda fructosa*, all of which are indicators of soil salinity.

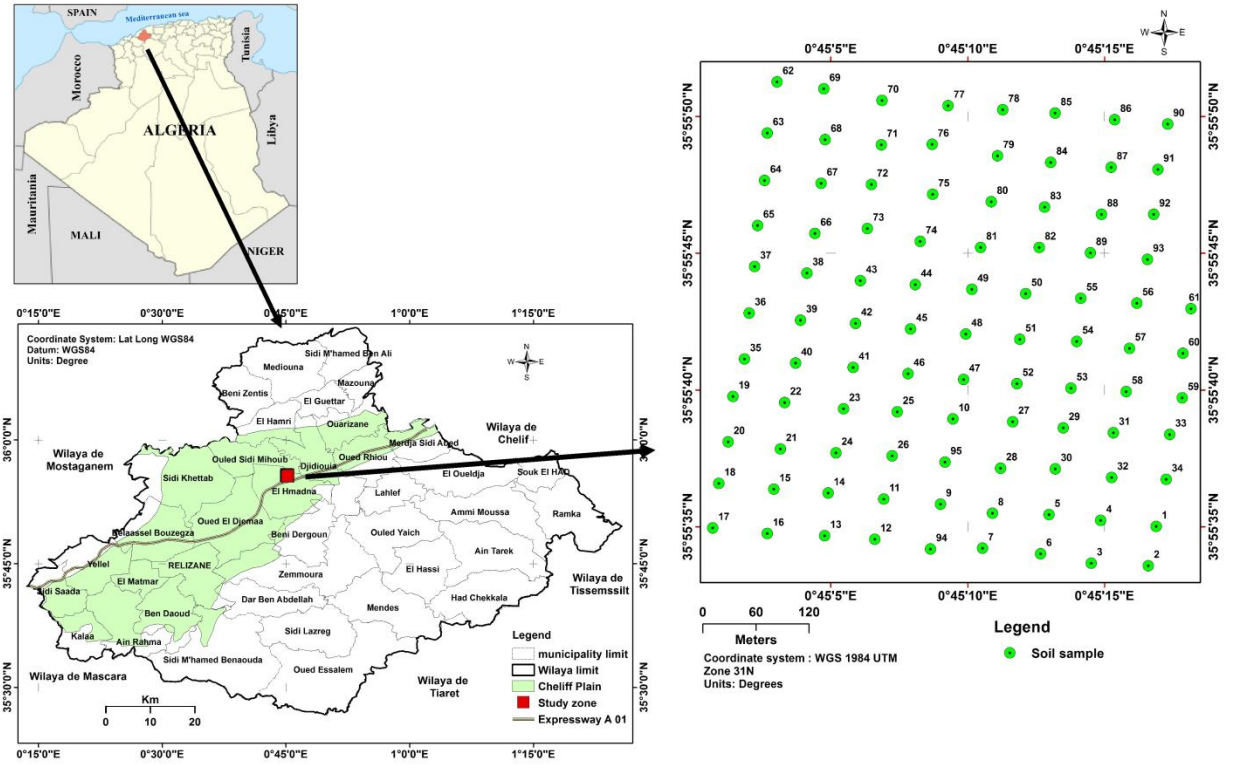

Figure 1. Location of the study area

Sampling device and measured parameters

The experiment was performed during the period from November 2019 to February 2020. Sampling on the study plot was conducted in a 50 m grid resulting in 95 measurement points (Fig. 1) located by GPS device. HCs was measured using a disk infiltrometer with a main reservoir with a diameter of 4.45 cm and a porous disk with a diameter of 20 cm. The method entails applying a water supply on the soil surface through the porous disk to measure the axisymmetric infiltration flow of water into the soil. During each measurement, a pressure value h, expressed in terms of water column height, is fixed and the water level in the reservoir is monitored throughout the infiltration process. The multi-potential steady-state Ankeny method was employed to measure HCs (Ankeny et al., 1991).

Methods of analysis

Soil samples were collected with an auger to a depth of 20 cm, which corresponds to the depth of the root zone of the crops cultivated in this area. Before measuring the investigated soil parameters, the soil samples were dried, crushed and sieved through 2 mm mesh sieves. The studied parameters included particle size (Richards, 1954), pH level and electrical conductivity of the saturated paste extract, bulk density, and soil moisture at the initial and final states of the HCs measurement (Carter & Gregorich, 2007).

Spatial Analysis

Soil water permeability and salinity level mapping was conducted by employing the ordinary kriging (OK) spatial interpolation method using ArcGIS10.3. This method entails interpolating the data of different soil parameters including: salinity status, particle size distribution, and hydraulic conductivity (Walter, 1990; Burrough & Donnell, 1998; Bradai, 2017; Berkane et al., 2021).

Statistical Analysis

Univariate and bivariate statistical analyses of the measured indicators were carried out using IBM SPSS (Statistical Package) Base 22.0 software with Excel Microsoft Office 2010.

RESULTS AND DISCUSSION

Spatial distribution of soil granulometry

Analysis of the particle size distribution reveals that clay and clay-loam textures occupy 63.73 and 13.56% of the surface area in the study plot, respectively (Fig. 2). The clay fraction ranges from 4.0 to 72.0% with an average of 44.0%, while the silt content varies from 16.0 to 72.0% with an average of 32.4% (Tab. 1). With clay and silt content of 76.4%, there is a potential for porosity clogging, which might reduce soil water permeability (Mathieu & Pieltain, 1998; Pousset, 2017).

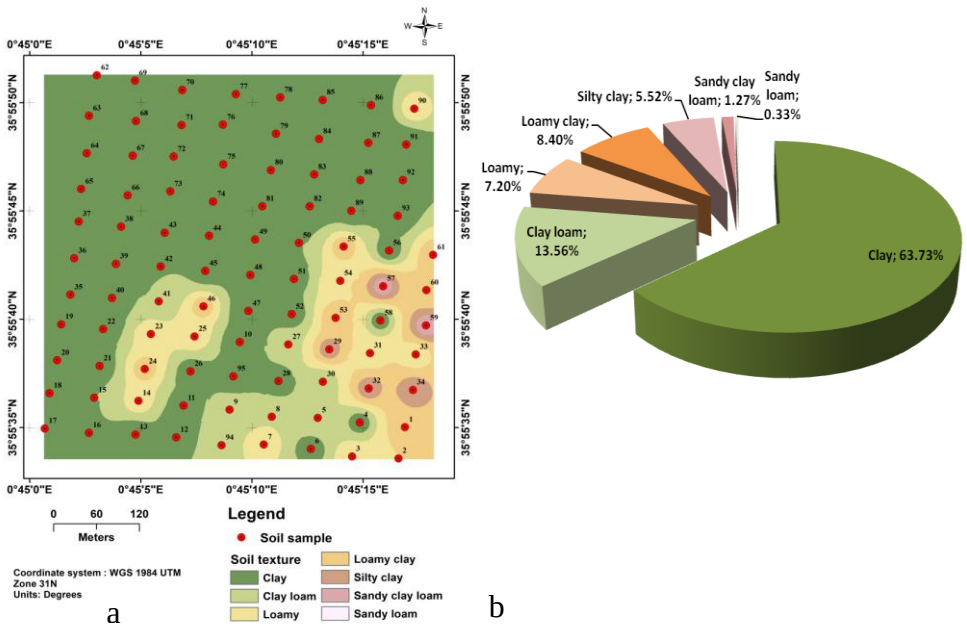

Figure 2. Soil texture in the experimental area: (a) spatial distribution of soil texture classes and (b) distribution of soil texture in percentage

Other indicators of soil quality show that the study plot is divided into three lots based on the coefficient of variation (Tab. 1). The method proposed by Warrick and Nielson (1980) was employed, based on an empirical model that assigns a large scale of comparison (Gagnon, 1996).

The first batch with a CV < 15% includes the following indicators: pH, initial soil moisture, and bulk density. The second batch with a CV between 30 and 100% includes soil texture, moisture at saturation, and HCs. In the third group with a CV > 100% there is only ECe, which ranges from 0.23 to 22.40 dS m^{-1} and it is a highly spatially dispersed indicator with a CV of 179.89% (Tab. 1).

Table 1. Parameters of investigated soil indicators in the study area

Statistics parameters	ECe (dS m^{-1})	pH	Hi (%)	Hs (%)	BD (g cm^{-3})	HCs (cm h^{-1})	Clay (%)	Silt (%)	Sand (%)
n = 95									
Min	0.23	6.18	3.95	16.02	1.05	0.30	4.00	16.00	4.00
Max	22.40	8.43	35.01	45.72	1.46	16.22	72.00	72.00	56.00
Average	1.75	7.77	19.34	34.57	1.26	3.80	44.00	32.40	23.58
Standard deviation	3.15	0.34	7.64	5.19	0.08	3.28	13.99	10.06	11.72
Variance	9.90	0.11	58.34	26.90	0.01	10.79	195.74	101.16	137.35
CV (%)	179.89	4.35	39.49	15.00	6.35	86.42	31.80	31.04	49.70

Legend: ECe – electrical conductivity of saturated paste extract; HCs – saturated hydraulic conductivity; Hi – initial soil moisture; Hs – saturated soil moisture; BD – bulk density; CV – coefficient of variation

Salinity of saturated soil paste extract

The spatial distribution of ECe is grouped into five classes (Fig. 3) according to the salinity scale established by the US Salinity Laboratory (Richards, 1954). No-saline class and slightly saline class account for 85% and 8% of the study plot area, respectively. The remaining 7% of the plot comprises saline soils with ECe levels exceeding 4 dS m^{-1}.

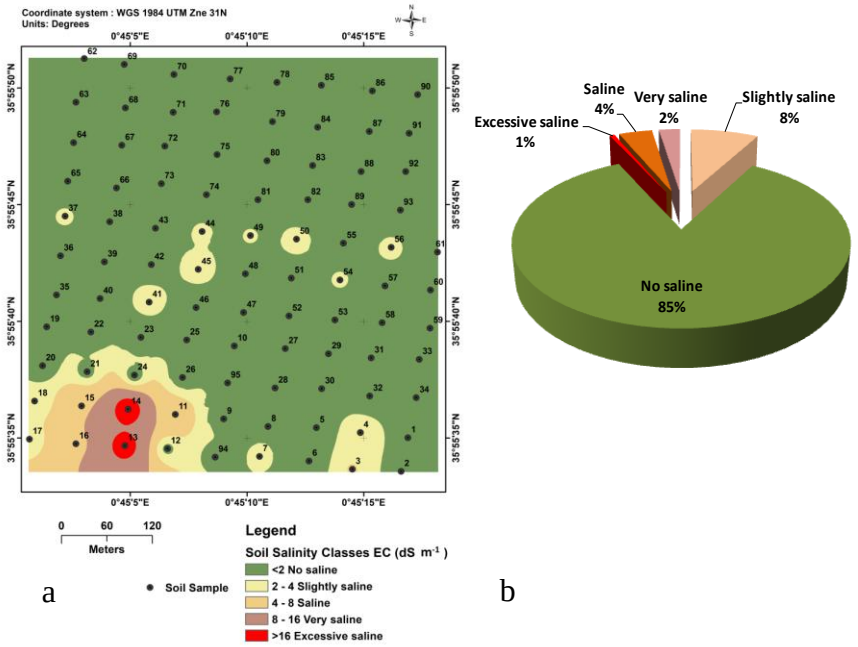

Figure 3. Soil salinity in the INRA-El Hmadena experimental area: (a) Spatial distribution of soil salinity by classes and (b) distribution of soil salinity in percentage

Soil Saturated Hydraulic Conductivity

The results of in situ measurements of soil HCs reveal four classes. The first class, characterized by moderate HCs, occupies nearly 77.97% of the total study plot area (19 ha). The second class, indicating moderately slow HCs, covers 11.29% of the total area, while the third class, representing moderately rapid HCs, accounts for 10.42% of the total area (Fig. 4). The average HCs = 3.80 cm h^{-1} appears to be consistent with the high content of fine fractions (clay and silt) of 76.4% (Mathieu & Pieltain, 1998; Tamoh & Maslouhi, 2004; INSID, 2008).

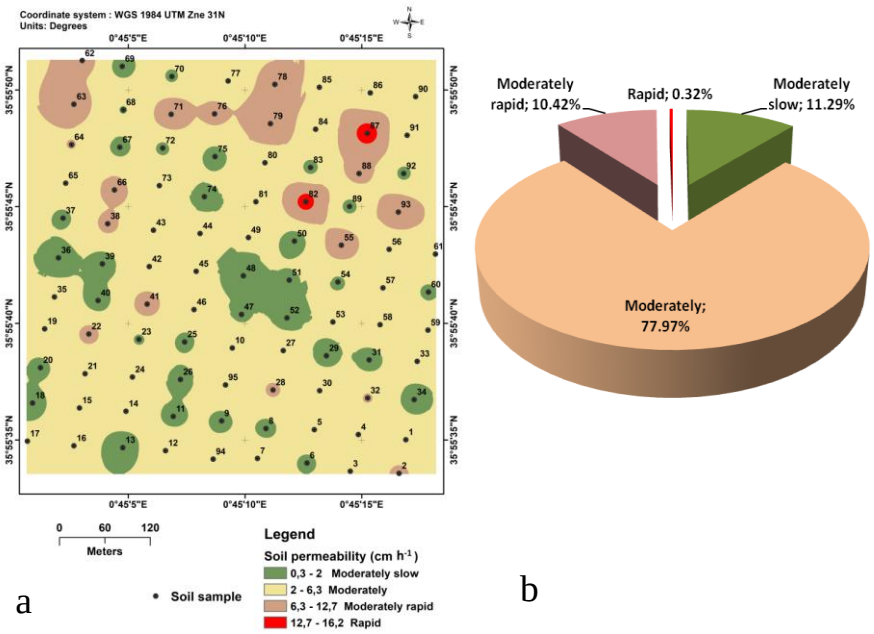

Figure 4. Hydraulic Conductivity saturate (cm h^{-1}) in the experimental area: (a) spatial distribution and (b) percentage distribution

Correlation between measured soil indicators

In order to highlight possible relationships between the measured soil indicators, correlations were established at a significance level of P < 5% (Tab. 2). The results reveal correlations linking initial and saturation moisture levels with clay content, as well as between soil pH and ECe of saturated paste extract.

Table 2. Correlations between different soil parameters

Parameters	BD	ECe	pH	Hi	Hs	HCs	Sand	Clay	Silt
BD	1.000								
ECe	0.178	1.000							
pH	-0.297**	-0.674**	1.000						
Hi	-0.323**	-0.174	0.326**	1.000					
Hs	-0.178	-0.001	0.167	0.716**	1.000				
HCs	0.053	-0.122	0.237*	0.261*	0.321**	1.000			
Sand	0.254*	-0.137	-0.002	-0.382**	-0.528**	-0.002	1.000		
Clay	-0.228*	0.112	0.082	0.470**	0.491**	0.058	-0.705**	1.000	
Silt	0.019	0.004	-0.110	-0.210*	-0.067	-0.077	-0.184	-0.567**	1.000

Legend: BD – bulk density; ECe – electrical conductivity of saturated paste extract; Hi – initial soil moisture; Hs – satura soil moisture; HCs – saturated hydraulic conductivity; * Significant correlation at 0.05 threshold (bilateral); ** Signifi correlation at 0.01 threshold (bilateral)

Soil HCs exhibit high spatial variability with a coefficient of variation of 86%. This extreme variability in the surface horizon has been consistently reported in literature (Vauclin, 1982; Coquet et al., 2000; Dewitte et al., 2012; Allbed et al., 2014; Wang et al., 2017). In-field investigations have examined spatial distributions of measured indicators such as saturated hydraulic conductivity, soil moisture, texture, and bulk density, revealing that coefficients of variation for soil water indicators often exceed those of physical indicators such as texture and bulk density (Carsel & Parrish, 1988; INSID, 2008; Berkane et al., 2021). In the surface horizon, 93% of the area is non-saline (85%) to slightly saline (8%). This phenomenon can be explained by the timing of soil sampling, which occurred after a period of substantial rainfall that reached 200 mm. Under such conditions, salt accumulation in the surface horizon is minimal as the salts leach out under the effects of precipitation, which is further facilitated by the presence of a functional drainage network within the surface horizon (at the depth of 20 to 30 cm).

To highlight the status of leached salts at depth, we examined ECe of the two lower horizons across six evenly distributed soil profiles within the study site (Fig. 5 and 6). The results indicate a progressive increase in salt concentration with depth, confirming the leaching of salts from the surface layer to the lower horizons. Moreover,

these findings confirm that the soil structure is not degraded and that it functions normally. The results obtained with the second soil quality indicator, HCs, also indicate that the structure is not degraded since 78% of the study area is within the moderate HCs class range (2 to 6.3 cm h^{-1}).

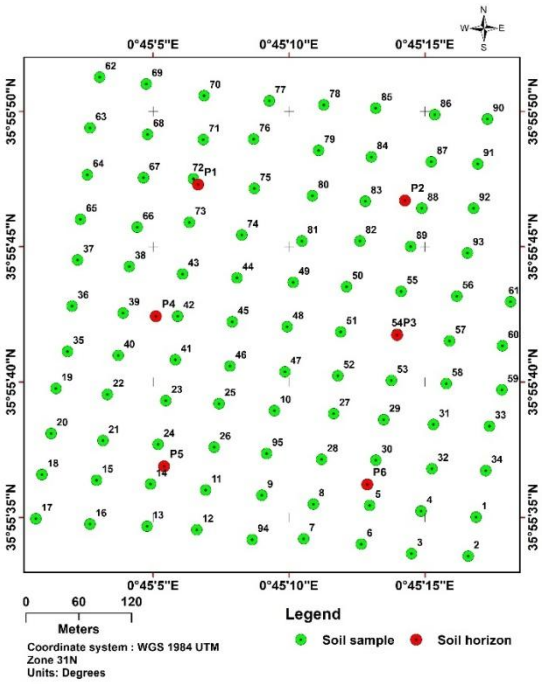

Figure 5. Location of soil profiles

It is important to note that using this diagnostic method based on ECe and HCs measurements can result in two scenarios, which determine the approach to optimizing irrigation and drainage management: (i) the soil structure is not degraded, as in the case of the present study, which requires preventive actions to control salinity through proper irrigation and drainage management practices by addressing deep salt leaching requirements, or (ii) the soil structure is degraded, which requires remedial measures by providing calcium amendments to rehabilitate soil structure and appropriate hydro-agricultural management practices. In each case, the deep-water drainage system must be perfectly functional. If the soil structure is not degraded, it is possible to predict the volume of irrigation that must be provided to ensure leaching of salts in depth during dry periods, which in the context of this study can last from March to October (8 months).

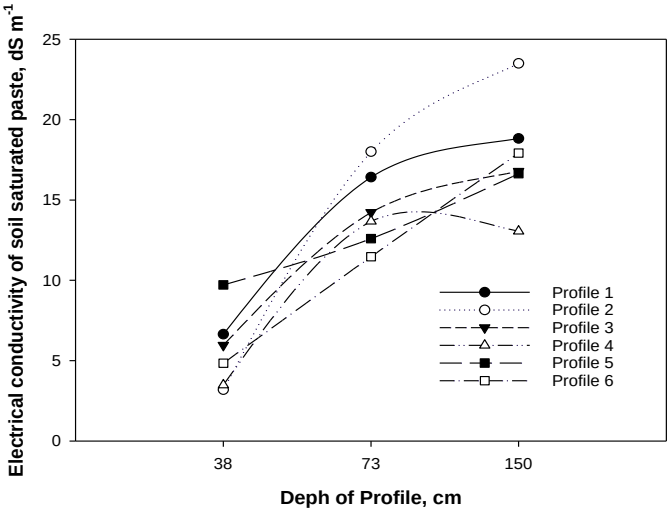

Figure 6. ECe (dS m^{-1}) in function of soil depth of profile (cm) in the experimental area

CONCLUSION

The results of the present study underscore the efficacy of employing both studied indicators of soil quality, ECe and HCs, for determining salinity status of soil in relation to its structural and permeability characteristics. This approach is recommended for hydro-agricultural management of irrigated perimeters susceptible to salinization. The approach is useful in the process of selecting appropriate irrigation and drainage practices aimed at regulating salinity levels in arid and semi-arid areas. By using this valuable tool, decision-makers can prioritize preventive or remedial measures to be taken in the early stages of salt contamination of soil, thereby ensuring the sustainability of agri-food production as well as soil health and water resources.

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Conflict of interest: The authors declare that they have no conflict of interest.

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