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Comparative Study on the Effect of Saline Water Irrigation on the Physico-Chemical Properties of Soils in the Mnasra Region, Gharb Plain, Morocco

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ABSTRACT

Soil salinity is a significant environmental challenge, particularly in arid and semi-arid regions, where irrigation water often contains high salt concentrations. This leads to salinization and alkalization, ultimately reducing soil fertility and agricultural productivity. This study assesses the effects of irrigation on soil properties with increasing NaCl concentrations, utilizing tap water (0.3 g/L NaCl) as the control, followed by 2.56, 5.12, 7.68, and 10.24 g/L of NaCl. The focus was on measuring sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺), chloride (Cl⁻) concentrations, along with pH, electrical conductivity (EC), and soil texture (granulometric analysis). In S₁ (clayey soil), saline irrigation increased pH to 7.63 and EC to 6.01 dS/m, with Na⁺ at 1.53 meq/L, K⁺ at 0.49 meq/L, and Cl⁻ at 14.2 meq/L. In S₂ (sandy soil), pH was 7.89, EC was 8.40 dS/m, Na⁺ was 5.9 meq/L, K⁺ was 0.8 meq/L, and Cl⁻ was 16.5 meq/L. SAR and ESP were also calculated, with S₂ showing higher values (SAR: 3.25 cmolc/kg, ESP: 5.3%) compared to S₁ (SAR: 2.52 cmolc/kg, ESP: 3.4%). Positive correlations were observed between salinity and the measured parameters. These findings provide valuable insights for developing effective salinity management strategies to promote sustainable agricultural productivity in affected region.

1. Introduction

Soil salinity poses a critical challenge to modern agriculture, affecting nearly 20% of arable land worldwide and is particularly problematic in arid and semi-arid regions [1-2]. This issue arises from a combination of natural and human-induced factors, such as inefficient irrigation, excessive fertilizer use, and climate change, all contributing to the accumulation of salts in soils [3-4]. This salinization process severely impacts agricultural yields, threatening both food security and the livelihoods of farmers [5].

Morocco, with its diverse climatic and geographic conditions, is especially vulnerable to soil salinity, particularly in key agricultural zones like the Gharb Plain [6]. This region, one of Morocco's major agricultural

production areas, is characterized by a Mediterranean climate ideal for cultivating cereals and vegetables. Nonetheless, inappropriate irrigation practices and outdated cultivation methods have exacerbated the salinity problem, jeopardizing agricultural sustainability [7].

In the Gharb Plain, particularly in the Mnasra region, the soils are predominantly clayey, which offers advantages in water retention but also presents challenges due to salt accumulation, especially during periods of prolonged drought or excessive irrigation [8-9]. Consequently, local farmers face significant challenges as salinity not only reduces crop productivity but also alters soil structure and reduces nutrient availability [10]. Recent studies have shown that salinity can cause yield losses of 30% to 50% in crops such as wheat and maize [11-12]. Understanding the

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mechanisms by which salinity affects plant growth is crucial for developing adaptive strategies. High soil salt concentrations impede the absorption of water and essential nutrients, disrupting fundamental physiological processes [13-14].

In this context, adopting sustainable management practices is vital to mitigate the harmful effects of salinity. Farmers are encouraged to implement techniques such as drip irrigation, the use of salt-resistant crop varieties, and improved soil management to reduce salt accumulation [15-16]. These strategies are particularly important in the Mnasra region, where agriculture remains a critical source of income for local communities.

The objective of this study is to thoroughly examine the effects of saline irrigation on the physico-chemical properties of S_1 and S_2 in the Mnasra region. The study will focus on size distribution, pH, electrical conductivity (EC), and the concentrations of various ions such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl^-), aiming to understand how these parameters are influenced by salt accumulation in the soil. Special attention is given to the impact on key indicators such as the Sodium Adsorption Ratio (SAR) and the Exchangeable Sodium Percentage (ESP), which are critical for assessing soil degradation under saline stress. This region, prone to saline stress, is the subject of this comparative study, which focuses on assessing the impact of saline water irrigation on the physico-chemical properties of soils in the Mnasra region of the Gharb Plain, Morocco. The research aims to identify sustainable practices to mitigate the negative effects of saline irrigation, particularly on soil fertility and agricultural productivity. In arid and semi-arid regions such as Mnasra, effective irrigation management is crucial to counteract the risks of salinization and alkalization, ensuring the long-term sustainability of farming practices.

2. Materials and Methods

2.1. Description of the study area

The Mnasra region is an integral part of the Gharb basin in northwestern Morocco. It covers 1.2% of the country's land area, with 68% designated for agricultural use (UAA). The Gharb perimeter, to which our study region belongs, includes a portion of the southern Rifain depression, which serves as an outlet to the Atlantic. Its coverage extends from latitude $34^\circ N$ to $34^\circ 45' N$ along the coast.

It is characterized by the predominance of sandy formations of marine origin along the riparian zones of the Sebou River, mixed with fine-textured alluvial deposits. Further back, merjas and sandy soils form the inland dunes. Finally, near the Gharb plain and along the banks of the Oued Sebou, sandy areas give way to recent Quaternary alluvium, rich in clay and/or silt (Fig. 1).

The Mnasra region, covering approximately 488 km², plays a crucial role in Morocco's agricultural production. Bordered by the Atlantic Ocean to the west and crossed by the Sebou River to the east, it enjoys a Mediterranean climate with oceanic influences.



Fig. 1. Geologic map of the study area.

Average temperatures range from $11^\circ C$ in winter to $27^\circ C$ in summer, creating favorable conditions for a diverse array of crops. Average annual rainfall is around 500 mm, primarily concentrated between November and April, with a dry period from June to September. Rainfall decreases from the coastal areas to the interior, with approximately 530 mm on the coast, 480 mm in intermediate zones, and 450 mm inland. While these climatic conditions support agriculture, they also require careful water and soil management to ensure sustainable farming practices, especially in light of challenges such as soil salinization.

2.2. Soil sampling

In February 2023, a soil sampling campaign was conducted in the Mnasra region, targeting both clay and sandy soils due to their agricultural significance and sensitivity to salinity. Soil samples were collected at depths of 0 to 20 cm and 20 to 40 cm using an auger to ensure precise collection. Each sample was carefully preserved to avoid contamination. Following collection, the samples were air-dried and ground to pass through a 2 mm sieve in preparation for a series of analyses. These samples were then transported to the Water and Soil Chemistry Laboratory of the Research Unit on Environment and Conservation of Natural Resources (CRRAR), INRA, in Rabat, where a comprehensive study of their physicochemical properties was carried out.

2.3. Irrigation and Salinity Treatment Protocol

Four saline treatments were applied to assess the impact of different NaCl concentrations on the physico-chemical properties of two soil types: S_1 (clay soil) and S_2 (sandy soil). The control treatment (C0) used tap water with 0.3 g/L NaCl, while treatments C1, C2, C3, and C4

contained 2.56 g/L, 5.12 g/L, 7.68 g/L, and 10.24 g/L NaCl, respectively. Each pot contained 4 kg of sieved (2 mm) S₁ or S₂, with non-perforated bases to prevent drainage and the leaching of salts. Saline solutions were uniformly applied to the soils via containers. Irrigation was performed at a rate of 300 ml per pot, twice a week, maintaining consistent moisture levels throughout the experiment. Soil samples from both soil types were taken at different growth stages to evaluate the physico-chemical changes induced by the saline treatments.

2.3. Soil Physical Properties

The soil particle size distribution was analyzed using the sedimentation method [17]. This method relies on the sedimentation velocity of particles, which varies depending on their size and density in a liquid, under the influence of gravity. A chemical treatment, using dispersing agents such as sodium hexametaphosphate, is applied to disperse the particles. After dispersion, particles settle according to their size, with larger particles settling more quickly than smaller ones. The granulometric distribution curve is constructed based on successive density measurements.

2.4. Soil Chemical Properties

The soil pH was measured potentiometrically using a Mettler Toledo Seven Easy-728 pH meter. For this measurement, a soil suspension was prepared in a weight-to-volume ratio of 1:2.5 with distilled water, and the measurement was conducted after stirring for 30 minutes, following the recommended methods [1]. Electrical conductivity (EC) was assessed from a saturated soil paste extract, obtained by mixing the soil with water until saturation, followed by measurement with an Orion model 162 conductivity meter, which allows for the evaluation of dissolved salt concentrations [2]. The concentrations of exchangeable potassium (K⁺) and sodium (Na⁺) were determined using flame photometry with a Jenway PFP7 flame photometer. This method requires prior treatment of the soil with an ammonium acetate solution to extract the exchangeable cations [1]. Exchangeable calcium (Ca²⁺) and magnesium (Mg²⁺) were quantified by atomic absorption spectrophotometry using a novAA 800 D analyzer, which measures the absorption of light by vaporized atoms [1]. Finally, chlorides (Cl⁻) were quantified using the Mohr method, which involves the reaction of chloride ions with silver ions (Ag⁺) to form insoluble silver chloride (AgCl) precipitate. Following the complete precipitation of chloride, a slight excess of silver ions is added, leading to the formation of a reddish-brown silver chromate (Ag₂CrO₄) in the presence of chromate ions, which serves as an indicator for the end point of the titration. Throughout this process, the pH of the solution is carefully maintained between 5 and 9.5 to ensure effective precipitation of the chloride ions, optimizing the accuracy of the measurement. This method is widely recognized for its reliability in quantifying chloride concentrations in various samples [3]. Additionally, the

assessment of soil sodicity was carried out by calculating the Sodium Adsorption Ratio (SAR) and the percentage of exchangeable sodium (ESP). The SAR is calculated using the following formula [21]:

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}] + [Mg^{2+}]}{2}}} \tag{1}$$

where [Na⁺] represents the concentration of sodium in the soil, and [Ca²⁺] and [Mg²⁺] denote the concentrations of calcium and magnesium cations, respectively.

The ESP is determined using the following formula [22]:

$$ESP = \frac{[Na^+]}{CEC} \times 100 \tag{2}$$

where [Na⁺] refers to the exchangeable sodium, and CEC indicates the total cation exchange capacity of the soil.

1.1. Statistical analysis

The Statistical analysis of the data was performed using SPSS (version 25). Descriptive statistics (min, max, mean, standard deviation) were calculated to examine variations in the parameters. Pearson correlation analysis was conducted to evaluate the relationships between soil physico-chemical properties and NaCl concentrations. Linear graphs were created to illustrate the interactions between SAR and ESP with other parameters.

2. Results and discussion

2.1. Particle Size Analysis and Textural Classification

Figure 2 shows the results of the granulometric analysis, indicating that S₁ consists of 50% clay, 35% silt, and 15% sand, classifying it as a clay-loam soil. In contrast, S₂ is composed of 80% sand, 10% clay, and 10% silt, classifying it as a sandy soil, according to soil classification criteria.

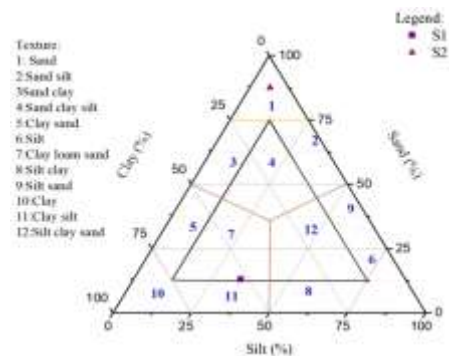


Fig.2. Soil texture triangle for S1 and S2.

2.2. Descriptive Statistics

The findings of the statistical summaries of the physicochemical properties of the soils listed in Table show significant differences between soil S1 (Silty-Clay) and soil S2 (Sandy). Soil S1 recorded pH values ranging

from 6.61 to 7.99, with an average pH of 7.23, while soil S2 had a pH between 7.35 and 8.33, averaging 7.73. These variations are especially noticeable across the three sampling periods, with a general trend of pH increasing as salinity rises. For the first sampling, pH values fluctuated from 7.10 to 8.20, with a mean of 7.53, reflecting relatively low salinity conditions. In the second sampling, pH values varied from 7.20 to 8.30, with an average of 7.74, indicating a slight increase in pH in response to higher salinity. Finally, in the third sampling, pH values ranged from 7.30 to 8.70, with a mean of 7.89, showing a more significant pH increase due to further salinization, especially in soil S2 (Fig. 2). Soil pH plays a crucial role in nutrient availability, which affects plant growth. In soils with more acidic conditions, such as soil S1, certain micronutrients like iron, zinc, and manganese become more soluble and are more readily absorbed by plants. This is especially true in slightly acidic environments [23]. However, in soils like S2, with a higher pH, the availability of these essential nutrients, particularly iron and zinc, decreases, limiting their absorption by plants [24-25]. Soil S2 has known advantages in terms of permeability and aeration. However, the increase in pH due to higher salinity can reduce the solubility of essential nutrients, making it less suitable for crops that are sensitive to alkaline conditions [26]. The elevated pH in saline soils can further restrict nutrient uptake, especially for elements like iron and zinc [27]. In contrast, soil S1, with its slightly lower pH, provides better conditions for nutrient availability, particularly in moderately saline environments. This is in line with previous research showing that moderate pH levels support better nutrient management in slightly acidic soils [28].

Table 1
Statistical characterization of the chemical properties of soil.

Soil type	Descriptive analysis	pH	EC	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻
S ₁	Maximum	8.20	9.80	1.53	4.70	5.00	7.6	15.60
	Mean	7.65	5.20	0.67	3.11	3.00	5.4	11.64
	Minimum	7.10	0.60	0.49	1.53	4.00	3.2	7.69
	STDV	0.35	3.40	0.11	0.91	0.61	0.73	1.54
	Variance	0.12	11.56	0.01	0.83	0.37	0.53	2.37
S ₂	Maximum	8.70	15.80	1.14	7.30	7.70	9.20	18.40
	Mean	8.00	8.50	0.82	5.41	6.65	8.35	16.60
	Minimum	7.30	1.20	0.50	3.52	5.60	7.50	14.80
	STDV	0.55	5.32	0.20	1.15	0.76	0.56	1.32
	Variance	0.30	28.31	0.04	1.32	0.58	0.31	1.74

The electrical conductivity (EC) of soil is a key indicator of soil salinity and nutrient availability, directly affecting plant growth and soil fertility [29]. Soils S1 and S2 show notable differences, with S2 having a maximum EC of 15.80 dS/m compared to 9.80 dS/m for S1. On average, the EC of S2 is 8.50 dS/m, while S1's average is 5.20 dS/m, indicating a higher salinity in S2. This elevated salinity can restrict the availability of essential nutrients such as potassium (K⁺), calcium (Ca²⁺), and magnesium (Mg²⁺), limiting water uptake and causing osmotic stress in plants [30-31].

Potassium (K⁺) is an essential nutrient that influences many vital soil processes, such as photosynthesis, water regulation, and enzyme activation [74]. In this study, soil S2 shows a higher concentration of K⁺ (1.14 meq/L) compared to soil S1 (0.67 meq/L), suggesting that S2 might offer better potassium availability. However, high salinity levels, such as those observed in soil S2, can limit K⁺ absorption, as competition among cations increases, reducing its absorption efficiency by the roots. This phenomenon is well-documented in recent studies, which show that salinity can affect nutrient uptake, including potassium, by disrupting ionic transport mechanisms in saline soils [32-33].

2.3. Relationships in Soil Physico-Chemical Properties

The correlation analysis performed in this study revealed significant relationships between electrical conductivity (EC) and the concentrations of sodium (Na⁺) and chloride (Cl⁻), with strong positive correlations (r = 0.801 for Na⁺ and r = 0.632 for Cl⁻) (Table 2). These findings confirm a close relationship between salinity and the accumulation of these ions, consistent with recent studies [36], which observed that increased salinity in saline soils is directly associated with higher concentrations of Na⁺ and Cl⁻. A negative correlation (r = -0.349) between Na⁺ and K⁺ was also identified, indicating that potassium uptake decreases with increasing salinity, a phenomenon well documented in the literature [37], where competition between these two cations under saline stress has been extensively explored.

Table 2
Correlation coefficients between soil physicochemical properties.

	pH	EC	k ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻
pH	1						
EC	-0,4543	1					
k ⁺	0,6499	0,7174	1				
Na ⁺	0,5987	0,8013	0,3486	1			
Ca ²⁺	0,7395	0,5832	0,5025	0,6994	1		
Mg ²⁺	0,6694	0,9650	0,5198	0,7513	0,7726	1	
Cl ⁻	0,9553	0,6322	0,5736	0,6821	0,6520	0,6976	1

Furthermore, the positive correlations between calcium (Ca²⁺) and magnesium (Mg²⁺) with EC (r = 0.583 for Ca²⁺ and r = 0.650 for Mg²⁺) suggest that these ions are also influenced by soil salinity. Recent studies have observed that high Na⁺ concentrations reduce the availability of Ca²⁺ and Mg²⁺ in saline soils, potentially impacting plant health and their ability to absorb these essential nutrients [38-39]. Lastly, the strong correlation between Na⁺ and Cl⁻ (r = 0.682) reinforces the idea that these ions are often present together in saline soils, a fact well-documented in recent studies, where co-accumulation of Na⁺ and Cl⁻ is frequently observed in saline environments [40-41].

2.4. Effects of Soil Parameters on SAR and ESP in Soils

2.4.1. Effect of Soil Salinity on SAR and ESP

Tables results presented in Figure 3 indicate that electrical conductivity (EC) and sodium concentration (Na⁺) have a direct influence on the two main salinity indicators, namely SAR and ESP. First, an increase in EC is correlated with a significant rise in SAR, reflecting sodium accumulation in the soil. This indicates that as conductivity increases, there is a greater presence of Na⁺ ions, leading to increased dispersion of clay particles and higher sodium saturation. These phenomena reduce cation exchange capacity (CEC) and negatively impact soil structure, which is well-documented in recent studies [42].

The relationship between Na⁺ and SAR is also notable. An increase in Na⁺ in the soil is associated with an elevation in SAR, reflecting an ionic dilution effect in the soil. Since SAR represents the ratio between sodium and calcium/magnesium concentrations, a high Na⁺ concentration, without an equivalent amount of calcium/magnesium, disrupts the ionic balance and leads to a loss of soil structure, thus increasing particle dispersion and affecting water infiltration [43].

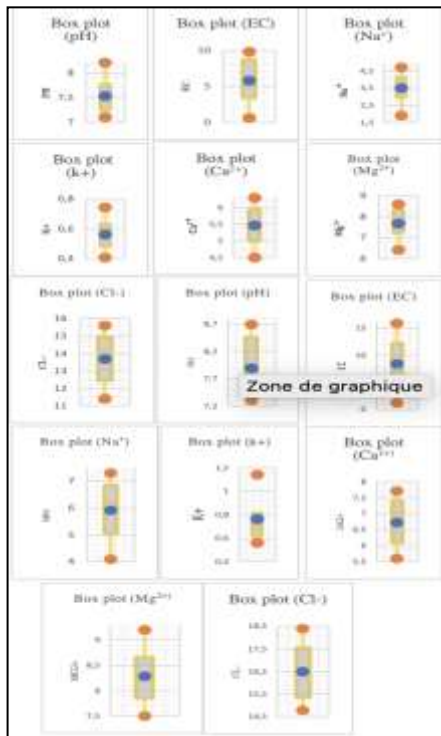


Fig. 3. Score Variability of Soil Data from First and Third Sampling.

As for ESP, it is also directly influenced by Na⁺ and EC. An increase in EC is associated with a rise in ESP, which shows an increased sodium saturation of the soil. This results in reduced water retention capacity and changes in permeability properties, potentially limiting nutrient availability for plants. This relationship is supported by the findings of [44], who report that managing salinity by optimizing the sodium/calcium ratio

is crucial to preserving soil structure and hydrological properties.

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Conflicts of interest statement

The authors declare no competing financial interests.

3. Conclusion and perspectives

This study aimed to analyze the physical and chemical properties of two soil types, S1 (clay-loam) and S2 (sandy), to assess the impact of salinity on their characteristics and fertility potential. The results show that the pH in soil S2 reached a maximum value of 8.33, while in S1, it peaked at 7.99, indicating a general trend of pH increase with rising salinity. Additionally, the electrical conductivity (EC) of soil S2 was significantly higher, reaching 15.80 dS/m, suggesting a more pronounced salinity compared to S1 (9.80 dS/m).

The analyses of the SAR and ESP show that high salinity in soil S2 leads to greater sodium saturation, which affects the soil structure and its cation exchange capacity (CEC), potentially causing water infiltration problems and reduced nutrient availability. In contrast, soil S1, while slightly more acidic, appears better able to manage sodium levels, making it more favorable for certain crops under moderate saline conditions.

These results highlight the importance of salinity management in agriculture, particularly for sandy soils where sodium levels are higher. To minimize the negative impacts of salinity, it is recommended to adopt practices such as using salt-tolerant plant varieties and improving irrigation techniques, especially in regions affected by increasing salinity levels. Future research should focus on more sustainable approaches to restore soil fertility, such as the application of organic amendments or phytoremediation strategies.

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