The effect of Electrical Conductivity on Physical and Chemical Properties of Different Types of Soil

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Abstract

This study aimed to assess and analyze the physical characteristics and chemical compositions of soil samples obtained from various locations, examine their relationship with electrical conductivity (EC), and assess their role in determining soil quality. Soil samples were obtained from two agricultural regions, Al-Buaitha and Al-Hamdiya, in Ramadi City, Anbar Governorate, Iraq, during the 2023–2024 period. Standardized procedures from the literature were followed to analyze soil properties using Elico Ultraviolet-visible (UV-Vis) spectrophotometry, atomic absorption spectrophotometry (AAS), and flame photometry. EC measurements were conducted using a conductivity meter. The results indicated considerable variation in the physicochemical properties of the different soil samples across different locations. A significant positive correlation was observed between EC and clay content ($r = 0.6$), water content (WC) ($r = 0.571$), and phosphorus (P) ($r \approx 0.6$). Additionally, EC showed a moderate positive correlation with silt content ($r = 0.470$), soil pH ($r = 0.436$), potassium (K) ($r = 0.492$), sodium (Na) ($r = 0.471$), and nitrogen (N) ($r = 0.361$). These findings suggest that EC can serve as an indirect indicator of key soil attributes, including fertility, water retention capacity, moderate salinity levels, and the presence of key nutrients required for plant growth. These findings provide valuable insights for soil conservation efforts and sustainable management strategies aimed at mitigating soil salinity and enhancing crop productivity and quality.

Keywords: Physical Properties, Chemical composition, Soil Types, Electrical Conductivity, Correlation Coefficient .

Introduction

Soil is a critical natural resource composed of complex components. It consists of a group of organic materials and mineral elements, in addition to water and air [27,23]. Soil quality significantly impacts agricultural productivity, climate, and water quality due to its essential role as a medium for plant and crop growth, as well as its function in regulating water flow, conserving groundwater, and facilitating nutrient cycling [9,8]. Given the impact of erosion factors and agricultural practices on soil quality, soil quality must be assessed by identifying and measuring its properties periodically [27] as soil quality assessment must reflect its physical characteristics and chemical compositions and the various processes and interactions that occur between them [27,17]. In addition, the physical properties of soil and its chemical components vary widely across areas and locations, which affects soil fertility, structure, quality, and suitability for different uses. Moreover, soil is dominated by a group of interactions between water and its solid components that directly affect soil properties and fertility [9,18]. Therefore, focusing on studying soil properties is important because it is a tool for measuring

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fertility between different types of soils. Furthermore, it provides essential information for distinguishing between soil types and understanding their responses to fertilization [9,18.[
The study of soil properties is also important for carrying out various human activities including agriculture, landscaping, recreation, environmental protection, and civil engineering [31,4]. The physical characteristics and chemical compositions of soil exhibit significant spatial and temporal variation, making the determination of these properties crucial for enhancing soil efficiency and promoting agricultural sustainability [31,27]. These properties are also pivotal and major studies in the fields of soil science, agricultural engineering, and civil engineering [4]. The physical characteristics of soil, including soil texture, structure, acidity, salinity, natural water content, density, depth, and electrical conductivity, play a crucial role in identifying soil types suitable for agricultural, horticultural, engineering, and environmental applications [30,36]. Additionally, these properties directly influence the biological and chemical characteristics of the soil and are related to its capacity to retain water and supply nutrients to plants [30.[
Concerning the chemical properties and components that depend on soil colloids and their collisions, studies have shown that these properties greatly affect soil diversity [20,29]. In addition, identifying the chemical components and their availability in soil is an indicator of the distribution and availability of nutrients necessary for plants [29]. Organic compounds are among the most important chemical components of soil and include carbon, calcium carbonate, and organic carbon (OC), as these compounds affect the structure and suitability of soil for planting and producing high-quality crops, in addition to their work on nutrient recycling in the soil and a substrate for microorganisms in it [38,27]. Furthermore, potassium, nitrogen, and phosphorus are the main chemical and nutritional components of the soil, as determining these elements is one of the factors that help maintain the level of fertilizers in agricultural soil, which achieves future sustainability in the field of agriculture [7,3.[
EC of soil is defined as the reciprocal of resistance and measures the soil's ability to conduct electricity. It is one of the least expensive and simple tools for measuring physicochemical soil characteristics that have played a vital role in assessing soil quality and precision agriculture [13,18]. Many studies have reported a strong correlation between EC and many physical and chemical soil properties [9,18,25 and 28]. The EC is an effective indicator for measuring the concentration and level of salts in the soil, water content, minerals, clay content, salinity (dissolved ions), and nutrients in the soil [25,9 and 18]. Due to technological developments in recent years, the use of EC in soil has witnessed many applications, such as engineering projects including modification methods of ground and the installation of buried high-voltage electrical power cables, as well as its use to monitor soil nutrients for scheduling fertilization and irrigation [25.[
Although determining soil's physical and chemical properties is important to achieve sustainability, whether in the agricultural field or other engineering projects in which soil is one of the basic pillars, studies related to this topic are rare in Iraq. Therefore, our current study focused on studying the physical properties of soil and chemical composition

and determining the relationship between them and EC for its role in assessing soil quality.

Materials and Methods

Description Study Site and Sample Collection

The present study was carried out between 2023 and 2024 in two agricultural regions, Al-Buaitha and Al-Hamdiya, located in Ramadi City, Anbar Governorate (Longitude: 33.486329° E, Latitude: 43.377374° N) and (Longitude: 33.486811° E, Latitude: 43.422556° N). These areas are situated along the banks of the Euphrates River in western Iraq (Figure 1). The two study areas are agricultural areas where temperatures drop to 18°C from December to February, and temperatures rise to 45°C from July to August, and the average annual rainfall is 1,643 ± 120 mm per year .

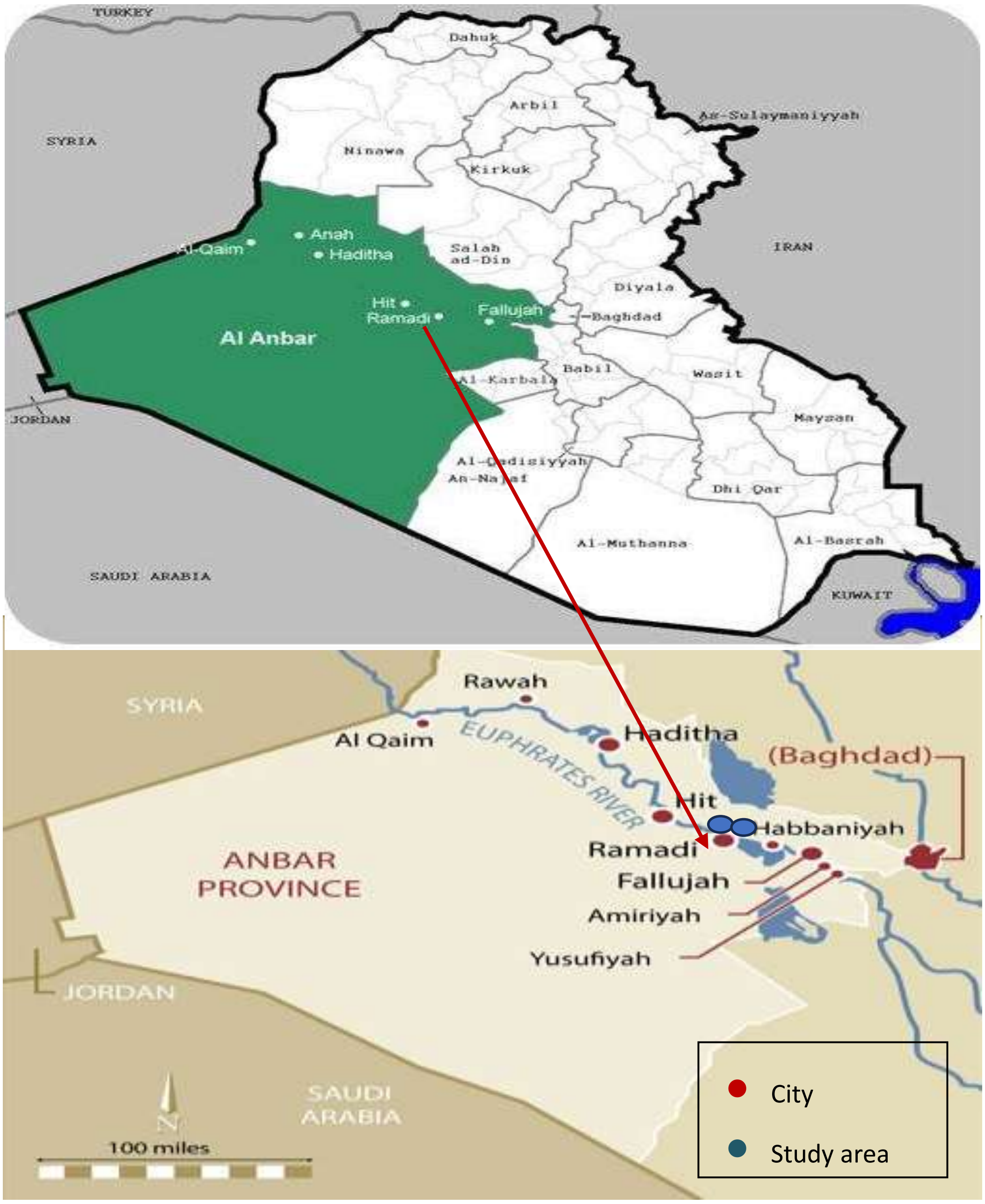

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Figure 1: Location of the soil sampling area under study for areas in the city of Ramadi, Anbar Governorate in Iraq.

Soil samples were collected from various locations within each area, with samples taken from bare surfaces at a depth of 10 cm using a sterile shovel. A total of nine samples (labeled A-I), each with distinct morphological characteristics, were collected (Figure 2) and stored in sterile polyethylene bags until analysis.

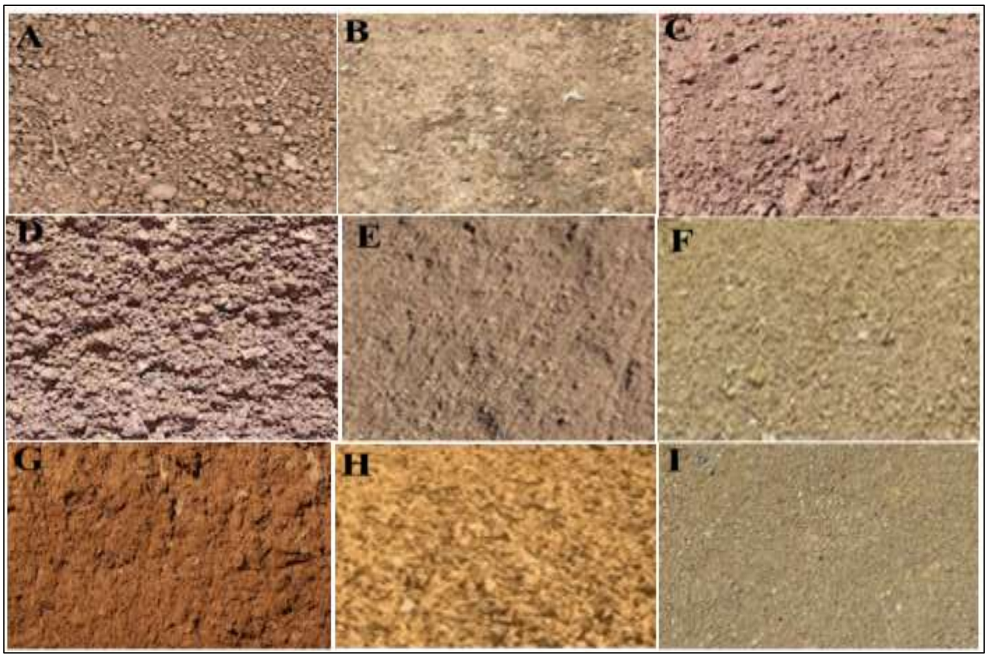

Figure 2: The soil samples collected from two distinct areas for analysis.

Analysis of Soil Sampling

Some analyses were performed at the Department of Soil Sciences and Water Resources, College of Agriculture, University of Anbar, while others were conducted at external research centers to assess the physical properties, chemical composition, and electrical conductivity (EC) of the soil. Soil samples were collected, dried in an oven at 105°C for 24 hours, and prepared for analysis. Before testing, the samples were air-dried and sieved through a 2 mm mesh [40]. The physical properties of the soil, including bulk density (BD), pH, water content (WC), specific gravity (SG), and soil texture, were determined. BD was measured using the core method after drying the samples to constant weight [11]. Soil pH was measured with a pH meter. The WC of the samples was determined by the gravimetric Embrapa method [10], while SG was measured using the pycnometer method. Finally, soil texture was analyzed by determining the proportions of soil texture (gravel, sand, silt, and clay) using the Embrapa absorbent method [10.[

The chemical characteristics and components of the soil were analyzed, including calcium carbonate (CaCO3), organic carbon (OC), phosphorus (P), potassium (K), nitrogen (N), sodium (Na), manganese (Mn), iron (Fe), zinc (Zn), and copper (Cu). CaCO3 content was

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determined using the Calcimetric method, which involves neutralizing acetic acid to find its equivalent. Organic carbon (OC) was measured using the Walkley-Black wet chromic acid digestion method [26]. Phosphorus (P) levels were analyzed by the molybdenum blue method, with phosphorus concentrations in soil samples measured using an Elico UV-Visible Spectrophotometer (Elico SL-218) at 750 nm. Nitrogen (N) was quantified using the modified titrimetric method based on the Kjeldahl procedure [6]. Potassium (K) and sodium (Na) were extracted from dried soil samples with a neutral ammonium acetate solution, and their concentrations were measured using a flame photometer (Elico CL-378). Finally, manganese (Mn), iron (Fe), zinc (Zn), and copper (Cu) were extracted with ammonium acetate and analyzed using an atomic absorption spectrophotometer (Elico SL-163) at the following wavelengths: 278 nm for Mn, 249 nm for Fe, 214 nm for Zn, and 325 nm for Cu.

The EC of the soil samples was measured by preparing a soil-water suspension. This was done by adding 20 g of dry soil to 50 ml of deionized water, creating a 1:2.5 soil-to-water ratio. The mixture was stirred to ensure thorough mixing of the soil with the water, then allowed to settle. The EC of the clear supernatant was subsequently measured using a conductivity meter (ELICO CM-183.(

Statistical Analysis

Statistical analyses, tests, data entry, and coding were conducted using the Statistical Package for the Social Sciences (SPSS) version 20 (IBM, USA). Data analysis and graph creation were performed using Excel. Pearson correlation coefficient analysis was employed to assess the relationships between EC and physical and chemical characteristics of soil samples, to determine if significant correlations existed [37.[

Results

Analysis of Physical Characteristics of Different Soil

The results related to the physical characteristics of the nine soil samples showed variations according to the sites from which they were collected (Table 1 and Figure 3). The BD values for nine samples ranged from 12 to 17 kN/m³, and CSZ3, DSZ4, and ISZ9 had the highest BD with values of 17 kN/m³, 16.61 kN/m³, and 16.40 kN/m³, respectively. While GSZ7 and HSZ8 showed the lowest BD with values of 12 kN/m³ and 13.50 kN/m³, respectively. The results also showed variation in the pH of the soil samples according to the sites from which they were taken, with values ranging from 5.1 to 7.5 (Table 1), indicating that the soil conditions varied from slightly acidic to somewhat neutral. ASZ1 and CSZ3 had the highest pH values of 7.5 and 6.7 respectively .

In contrast, GSZ7 had the lowest pH (5.1) and ESZ5 had (5.3). BSZ2, DSZ4, ESZ5, GSZ7, HSZ8 and ISZ9 had pH < 6.0 (Table 1). The specific gravity (Gs) of the soil sample ranged from 2.63 to 2.78, with DSZ4 showing the highest specific gravity (2.78). In comparison, ASZ1 showed the lowest specific gravity (2.63). The results showed notable variation in the values of the natural water content (NWC) for all soil samples, as the values ranged from 11.8% to 27%. GSZ7, ISZ9, and ESZ5 recorded the highest NWC with values of 27%, 26%, and 25.3%, respectively. While CSZ3 and ASZ1 recorded the lowest NWC with values of 11.8% and 12.5%. Finally, the results related to soil texture showed a noticeable variation in the percentage of soil texture (gravel, sand, silt, and clay) composition for nine samples. ASZ1, CSZ3, FSZ6, and HSZ8 had a sandy loam soil texture, BSZ2, HSZ8, and ISZ9 had a clayey loam soil texture, while DSZ4 and GSZ7 showed that they had a clayey and clayey loam texture, respectively (Table 1.(

Table 1. Displays the location and physical characteristics of the soil samples examined in the study.

Soil samples	location		BD (kN/m^3)	pH	SG (Gs)	NWC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	ST
	Longitude	Latitude									
ASZ1	43.2992	33.4258	15	7.5	2.63	12.5	3	65	18	14	Sandy loam
BSZ2	43.2995	33.4260	14.50	5.6	2.74	17.6	0	28	57	15	Silty-loam
CSZ3	42.8932	32.7262	17	6.7	2.68	11.8	1	68	19	12	Sandy loam
DSZ4	43.2971	33.4246	16.61	5.5	2.78	24.5	2	13	73	12	Silty
ESZ5	43.2852	33.4255	13.97	5.3	2.66	25.3	1	42	43	14	Loam
FSZ6	43.2996	33.4261	16.30	6.1	2.70	13.2	2	70	13	15	Sandy loam
GSZ7	42.7861	32.8462	12	5.1	2.69	27	0	33	21	46	Clay loam
HSZ8	43.2985	33.4253	13.50	5.7	2.71	18.5	0	26	60	14	Silty-loam
ISZ9	43.2994	33.4263	16.40	5.4	2.76	26	1	15	71	13	Silty

SZ: Sample zone; BD: Bulk density; NWC: Natural water content; SG: Specific gravity; ST: Soil texture.

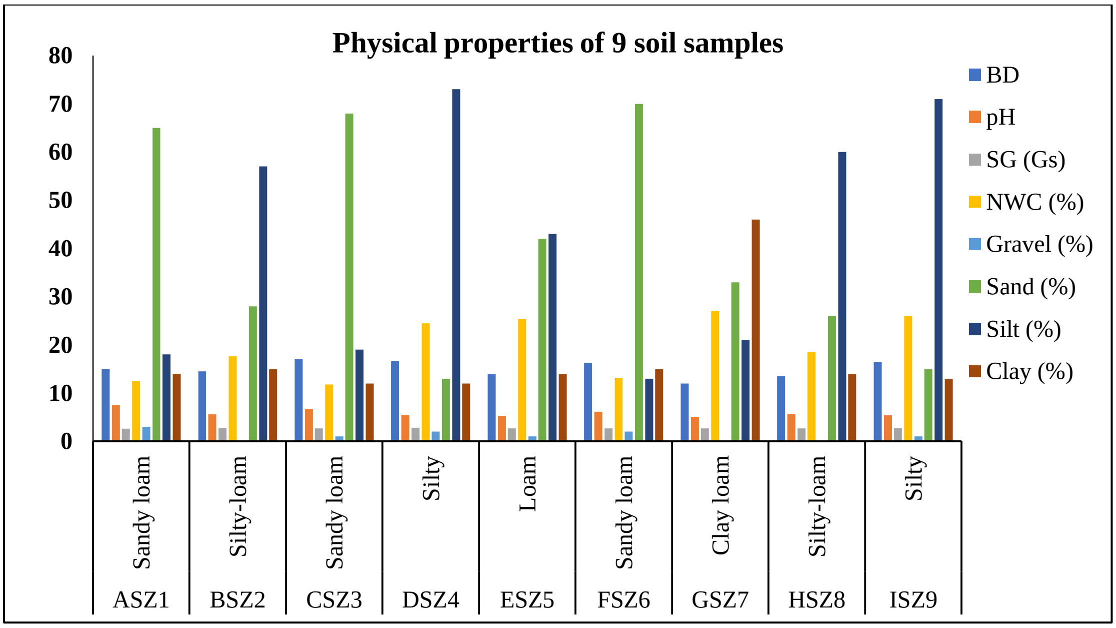

Figure 3: Shows the variation of physical characteristics according to location and soil type.

Analysis of Electrical Conductivity and Chemical Characteristics of Different Soil

The results related to chemical properties and electrical conductivity (EC) revealed notable variations in EC, chemical composition ($CaCO_3$ and OC), and essential nutrient availability for all soil samples as shown in Table 2 and Figure 4. The results related to EC revealed differences between soil samples, where EC values ranged from 25.64 mS/m⁻ ¹ to 201.40 mS/m⁻ ¹. The results revealed that GSZ7, ESZ5, and ISZ9 had the highest EC values 201.40, 187.35, and 170.89 mS/m⁻ ¹ respectively, and also had high CaCO3 content, with GSZ7 showing the highest value (20.51%) for CaCO3. The results also revealed differences in the OC, P, and N contents of all soil samples, with GSZ7 and ISZ9 having the highest levels of these chemical compositions (Table 2). This suggests that increased OC content contributes to increased P and N retention. The results regarding the distribution of K, Na, and micronutrients also revealed that soil samples GSZ7, ESZ5, and ISZ9 exhibited the highest concentrations of k, Na, and micronutrients (Fe, Mn, Zn, and Cu.(

Table 2. Shows the electrical conductivity and chemical composition of the soil samples under study.

Soil samples	EC (mS m^{-1})	$CaCO_3$ (%)	OC (%)	P (kg/ha)	N (kg/ha)	K (kg/ha)	Na (ppm)	Mn (ppm)	Fe (ppm)	Zn (ppm)	Cu (ppm)
ASZ1	27.31	2.60	0.16	12.53	156.50	144.30	2.43	1.624	5.24	0.257	0.975
BSZ2	76.16	10.23	1.62	21.35	210.15	289.13	47.12	58.11	36.10	2.17	3.30
CSZ3	25.64	1.84	0.12	11.21	134.14	139.61	1.961	1.468	5.11	0.239	0.893
DSZ4	155.10	16.37	2.18	39.41	274.48	369.11	75.91	65.84	110.21	3.73	4.51
ESZ5	187.35	11.92	2.34	47.11	286.12	401.31	91.16	79.45	128.61	4.11	5.42
FSZ6	28.50	3.32	0.29	13.76	186.13	163.80	3.14	2.131	6.81	0.421	1.26
GSZ7	201.40	20.51	3.72	59.79	305.16	475.81	112.59	93.97	168.21	5.75	6.72
HSZ8	82.20	12.43	1.86	24.15	245.11	294.61	53.18	64.19	41.20	2.53	3.94
ISZ9	170.89	18.57	2.94	46.11	311.28	391.20	83.21	71.14	115.13	4.62	4.78

Sample Zone (SZ); Electrical Conductivity (EC); Calcium Carbonate (CaCO3); Organic Carbon (OC); Nitrogen (N); Potassium (K); Sodium (Na); Phosphorus (P); Manganese (Mn); Iron (Fe); Zinc (Zn); Copper (Cu.(

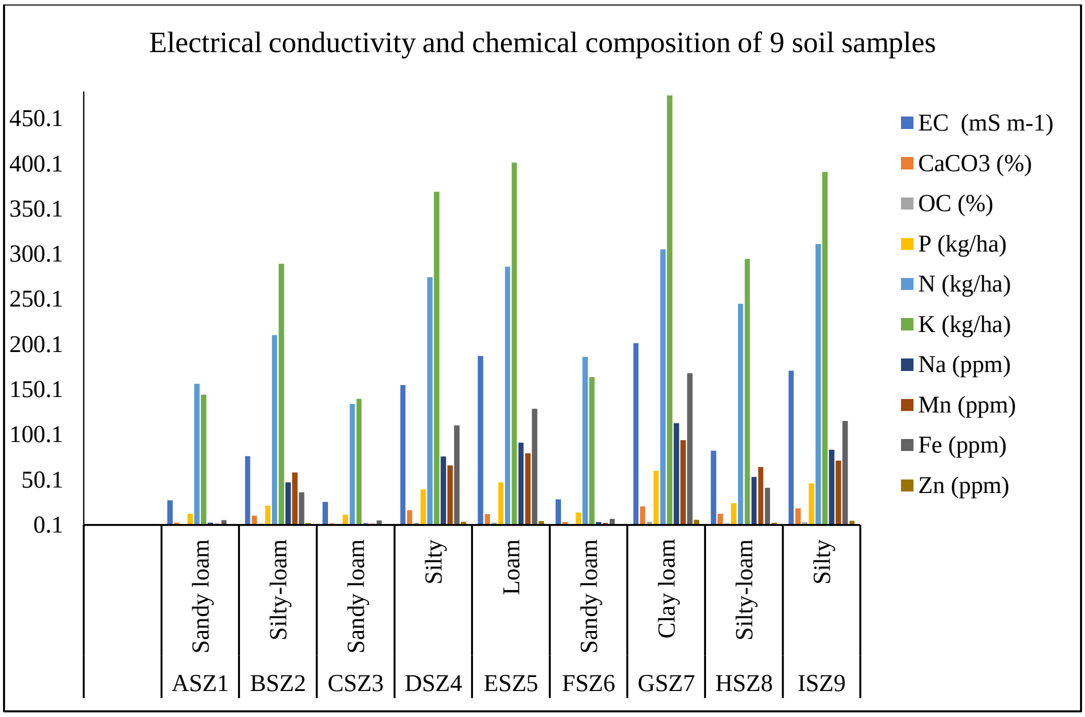

Figure 4: Shows the variation of electrical conductivity and chemical composition according to location and soil type.

Analysis of Correlation

The results of the Pearson correlation analysis between EC and physical soil properties, as well as chemical composition, are presented in Tables (3 and 4), with their relationships illustrated in Figures 5 and 6 .
The analysis revealed a strong positive correlation between EC and clay content (r = 0.6), and a moderate positive correlation between EC and silt content (r = 0.470). Similarly, a strong positive correlation was also observed between EC and natural water content (NWC) (r = 0.571), while the correlation between EC and soil pH was moderate (r = 0.436). Conversely, a negative correlation was found between EC and sand content (r = -0.348) and gravel content (r = -0.263) (Table 3). A weak positive correlation was observed between EC and bulk density (BD) (r = 0.131), as well as specific gravity (SG) (r = 0.102). and SG (r = 0.102.(

Table 3. Correlation coefficients between EC and physical characteristics of the soil samples under study

Physical soil parameters	EC (mS m^{-1})	BD (kN/m^3)	pH	SG (Gs)	NWC (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
EC Pearson Correlation	1	0.131	0.436	0.102	0.571	-0.263	-0.348	0.470	0.603

BD: Bulk density; NWC: Natural water content; SG: Specific gravity.

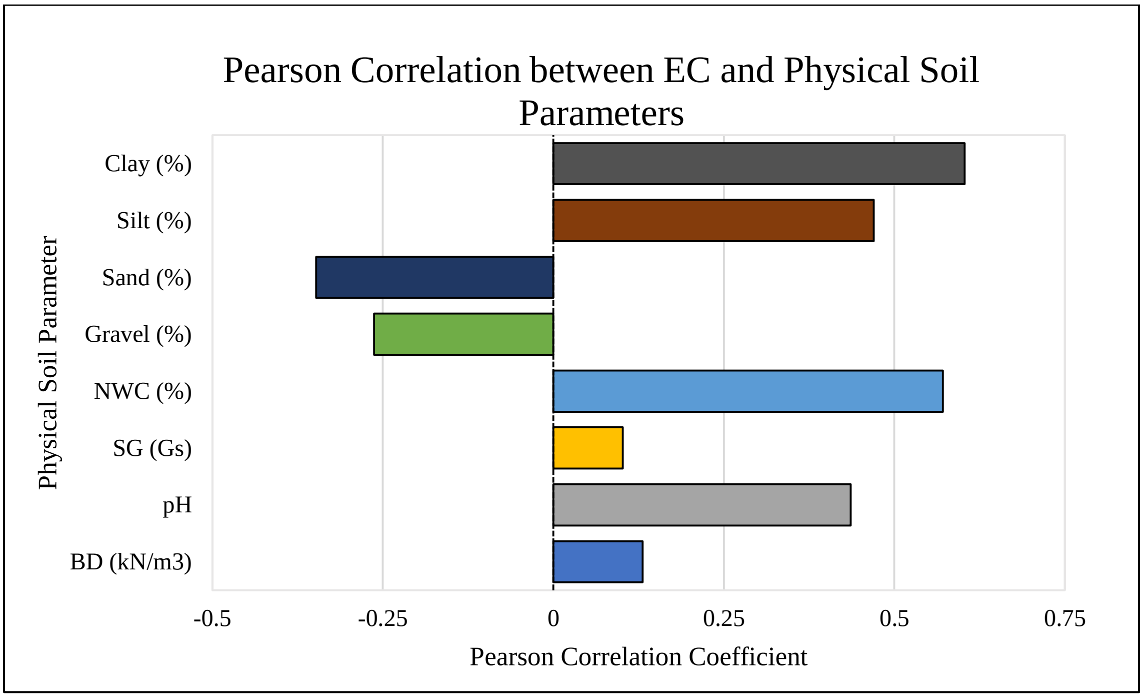

Figure 5: Representing the Pearson correlation coefficients (PCC) between EC and different physical soil properties.

In terms of chemical composition, the results indicated a strong positive correlation between EC and P (r ≈ 0.6). A moderate positive correlation was observed between EC and K (r = 0.492), Na (r = 0.471), and N (r = 0.361). Weak positive correlations were found between EC and OC (r = 0.062) as well as CaCO3 (r = 0.051). Similarly, Zn and Cu exhibited weak positive correlations with EC, with values of r = 0.031 and r = 0.016, respectively (Table 4). Conversely, the analysis revealed weak negative correlations between EC and Mn (r = -0.014) and Fe (r = -0.026), as presented in Table 4 and illustrated in Figure 6.

Table 4. Pearson correlation coefficients (PCC) between electrical conductivity and chemical composition of the soil samples under study.

Chemical soil parameters	EC (mS m^{-1})	$CaCO_3$ (%)	OC (%)	P (kg/ha)	N (kg/ha)	K (kg/ha)	Na (ppm)	Mn (ppm)	Fe (ppm)	Zn (ppm)	Cu (ppm)
EC Pearson Correlation	1	0.051	0.062	0.549	0.361	0.492	0.471	-0.014	-0.026	0.031	0.016

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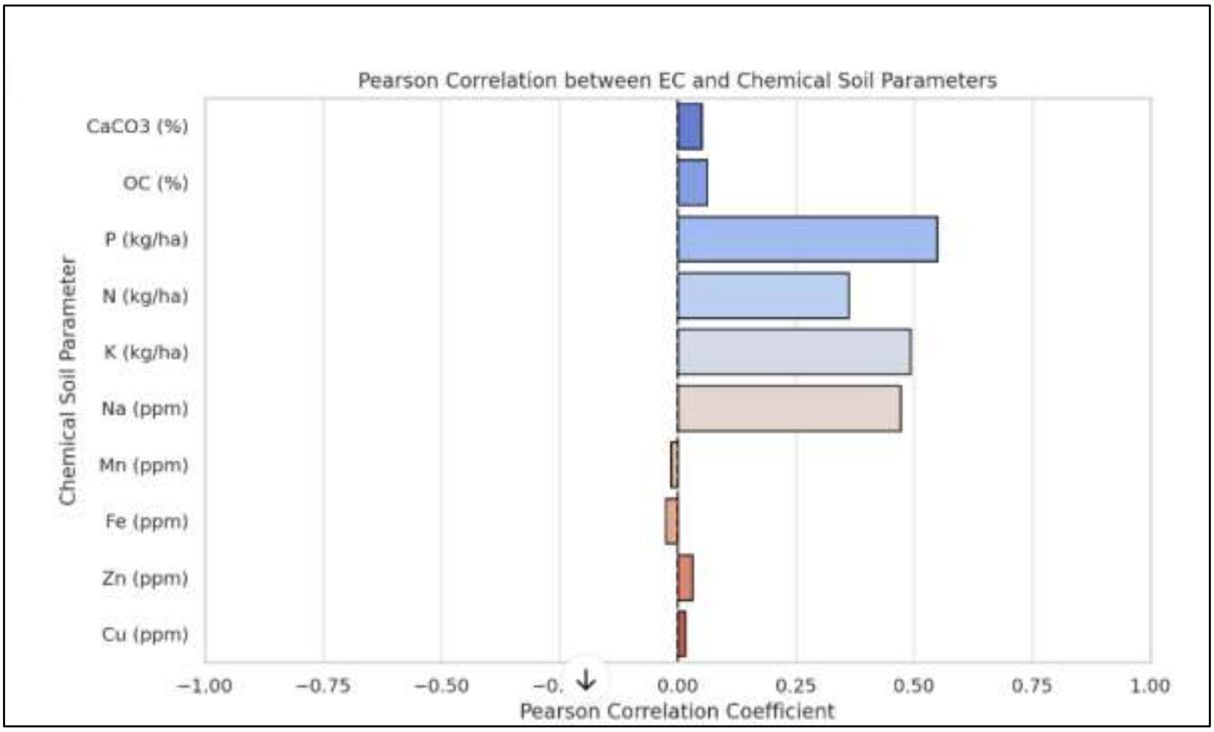

Figure 6: Representing the Pearson correlation coefficients (PCC) between EC and different chemical soil properties.

Discussion

The analysis of the physical and chemical characteristics of the nine soil samples revealed significant variations based on their respective locations. These differences are critical in assessing soil quality, particularly for agricultural applications, as they influence essential factors such as root penetration, water infiltration, and the soil's ability to retain both nutrients and moisture [15,41]. The observed variability in soil properties across different locations can be attributed to the agricultural nature of these lands. The cultivation of diverse plant species during different agricultural seasons, along with varied land use practices, can significantly impact the physical characteristics and chemical compositions of the soil [15.[

The presence of high bulk density (BD) values in certain samples suggests soil compaction, which can restrict root growth and impede air and water movement. Conversely, lower BD values indicate a more porous soil structure, which may enhance microbial activity and aeration. Given that the studied soils originate from agriculturally significant areas, determining BD is crucial, as it serves as an indicator of soil porosity, structure, and compaction. Previous studies have demonstrated that BD in cultivated soils tends to increase due to factors such as tillage, soil aggregation, root distribution, reduced organic carbon, and the cultivation of different plant species [1,15 .[

In terms of soil pH, the findings indicated that higher pH levels correspond to more favorable conditions for agriculture, as they promote nutrient availability and microbial activity. Furthermore, soil pH is a key parameter for

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evaluating soil quality across different land uses [34]. Acidic soil conditions can significantly influence microbial community composition and nutrient solubility, making them less suitable for cultivation. The acidic nature of most samples in this study is likely a consequence of agricultural practices, which can directly alter soil pH [5]. The majority of the soil samples exhibited pH values below 6, highlighting the need for soil amendments to mitigate potential aluminum toxicity, which could adversely affect microbial diversity and plant growth [32]. Additionally, the samples displayed high specific gravity (Gs) values, which may be attributed to the presence of heavier minerals such as iron oxides [24]. Variations in Gs values across different samples suggest differences in mineral composition and soil texture at the respective sites. Natural water content (NWC) is another critical factor influencing plant growth and microbial activity. The results showed that soils with higher clay content exhibited elevated NWC levels, with values reaching 46% in GSZ7. Similarly, [21] found that soils with a higher clay content (31.72%) retained more moisture compared to those with higher sand content. It is well established that clay-rich soils are more effective at retaining moisture than sandy soils [8]. Conversely, soils with a sandy texture showed reduced moisture retention due to their high drainage capacity [8,21.[

Soil texture is a fundamental physical property and is often used as an indicator for soil characterization in various studies. Approximately 70% of soil organic matter (OM), carbon (C), and nitrogen (N) are closely linked to soil texture [27,12]. The predominant soil texture identified in this study was sandy loam, which is characteristic of agricultural soils. This result is consistent with the findings of [12], who reported similar textures in three agricultural sites. Variations in soil texture influence nutrient retention and permeability. Notably, the ESZ5 sample was identified as highly suitable for cultivation due to its balanced composition of silt, sand, and clay, creating an optimal environment for plant growth.

The variations in the chemical properties of soil, including electrical conductivity (EC), reflect the diversity of soil characteristics such as salinity, potential fertility, and OM content across the sampled sites. The observed increase in EC in certain soil samples suggests elevated salinity and ionic concentrations, which can be attributed to higher clay and silt content, as well as the presence of minerals such as potassium (K) and sodium (Na) alongside organic matter. Additionally, the increase in EC is linked to a higher cation exchange capacity (CEC), which is influenced by both clay content and OM [39,3]. [35] also identified CEC, clay content, soil salinity, and moisture content as key factors affecting soil EC.

The findings of this study further support that an increase in organic carbon (OC) enhances phosphorus (P) availability and nitrogen (N) retention, which in turn influences microbial activity and its bioavailability [19]. Notably, some soil samples exhibited high concentrations of Na and K, contributing to increased salinity. This elevated salinity can negatively impact the solubility and bioavailability of micronutrients [22]. Additionally, considerable variation in K, Na, and micronutrient levels was observed, likely due to factors such as soil pH, OM content, salinity, and agricultural practices. These factors play a crucial role in regulating nutrient distribution within the soil types [22 .[

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Examining the relationship between EC and soil properties is essential for understanding the influence of various physical and chemical parameters. Correlation coefficients provide insights into how individual soil factors affect EC, offering a comprehensive perspective on soil texture, moisture dynamics, and ion movement [21]. The strong positive correlation between EC and clay content can be explained by the high moisture and nutrient retention capacity of clay-rich soils, coupled with their elevated CEC, which enhances ion retention and mobility. This finding aligns with previous research [16,2 and 39]. Moreover, the strong correlation between EC and natural water content (NWC) highlights the role of water in facilitating ionic mobility, further corroborating the results of [33]. The moderate positive correlation observed between pH and EC may be attributed to the increased solubility of salts under alkaline conditions, which promotes greater ionic mobility. This observation is consistent with previous studies demonstrating that alkaline soils often exhibit higher salt solubility, thereby increasing EC [14,23]. Furthermore, coarse-textured and sandy soils were found to have lower EC values, likely due to their limited capacity to retain water and dissolved salts, as well as their reduced surface area, which results in lower ionic conductivity.

The strong positive correlation between EC and elements such as P, K, Na, and N suggests that the presence of soluble salts contributes to increased salinity and enhances ion exchange processes, ultimately raising EC. These findings align with multiple studies that have confirmed the positive association between EC and these elements through Pearson correlation analyses [9,12 and 39.[

Conclusion

Our current study reveals significant variations in the physical characteristics and chemical compositions of soils from different agricultural locations. The findings indicate that soil texture, pH, BD, WC, EC, and nutrient composition play a crucial role in determining soil fertility, salinity levels, and microbial activity. Additionally, EC is influenced by various soil properties, including texture, pH, WC, and the presence of soluble salts such as P, K, and Na, which contribute to its increase. The strong positive correlations between EC and WC, pH, clay, silt, P, K, and Na suggest that EC can serve as an indirect indicator of soil fertility, water retention capacity, moderate salinity, and the availability of essential nutrients for plant growth. These findings provide valuable insights for soil conservation efforts and sustainable management strategies aimed at mitigating soil salinity and enhancing crop productivity and quality. Furthermore, improving soil fertility across different soil types requires targeted interventions. Future research should expand the scope of soil sampling and site selection to investigate microbial interventions and soil treatments that can enhance microbial activity, promote nutrient cycling, and support long-term soil sustainability.

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