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Research article

Evaluation of Selected Physical and Chemical Properties and Nutrient Status of Gypsiferous Soils in Al-Bu Tuma, Tikrit District, Iraq

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ABSTRACT

This research study aimed at describing the physicochemical characteristics of the soils of Al-Bu Tuma area, Tikrit district, Salah al-Din province, with the objective of measuring their salinity and fertility levels and to determine the impact of agricultural activities and fertilization on some soil characteristics. A total of 23 surface soil samples were collected from different sites at a depth of 0-30 cm representing soils of wheat, vegetable crops and fallow. Soil samples were subjected to important physical and chemical analysis such as bulk density, porosity, particle size distribution, soil pH, electrical conductivity (EC), organic matter, gypsum and calcium carbonate contents, in addition to measuring total nitrogen and available phosphorus. It was found that there are differences in some soil characteristics among the study sites. Values of bulk density were between 1.13 and 1.55 g cm^{-3} , porosity 41.51-57.36%, pH values 7.10-7.99, EC 2.14-4.86 dS m^{-1} . Organic matter content was between 3.3 and 27.2 g kg^{-1} . Values of gypsum content were between 60.3 and 143.3 g kg^{-1} , calcium carbonate 110 and 210.5 g kg^{-1} . Total nitrogen content was between 11 and 46 mg kg^{-1} , while available phosphorus was between 4.17 and 16.54 mg kg^{-1} . In general, the soils had high gypsum and calcium carbonate contents with high salinity, in addition to low organic matter and some nutrients.

1. Introduction

Soil is a very important natural resource that ensures ecosystem sustainability and agriculture. It provides an appropriate environment for plant growth and development, watering and providing plants with nutrients. Soil properties have spatial variability, determined by the factors affecting the development of the soil, such as type of parent material, climate, vegetation cover, and geomorphology processes (Gavrilescu, 2021). Gypsum soils have peculiarities depending on high gypsum content in them, and these peculiarities affect their physical and chemical properties. The variations of these properties are determined by the differences in the gypsum content and distribution in the soil profile, affecting such properties as structure, density, air permeability, soil aggregate stability, and some chemical properties (Kuttah & Sato, 2015). These properties also differ

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according to the type of parent material, environmental factors and soil formation and development processes. Physical properties of soil are very important criteria to evaluate soil condition since they directly relate to soil texture and its composition from sand, silt, and clay particles and affect the movement of water and air in the soil and soil moisture. Also, soil density, porosity, and weighted average particle size are very important characteristics that determine soil structure and aggregate stability and are affected by organic matter properties, vegetation cover, root activity, and other natural processes (Maurya et al., 2020). As far as chemical properties of soil, their importance is defined by the ability of the soil to ensure the physiological growth of the plants. Such chemical properties as pH, electrical conductivity (EC), organic matter (OM), Gypsum and calcium carbonate contents are considered part of the analysis. In addition to their basic role of determining the chemical composition of the soil environment due to the presence of dissolved and exchangeable ions, which include not only calcium, magnesium, sodium, and potassium but also sulfates, chlorides, and bicarbonates (Al-Soghir et al., 2022), such nutrients as nitrogen and phosphorus are among the main factors to indicate the fertility of the soil and the ability of the soil to meet the needs of plants. These nutrient contents are affected by various aspects, among which the amount of organic matter in the soil, soil pH, soil moisture, climatic factors, and mineralogical and chemical composition of the soil can be highlighted. Hence, assessing the available amount of nutrients allows identifying the status of soil fertility and factors affecting soil productivity. At the same time, soil salinity and sodicity are one of the significant problems that might affect soil properties and its productivity. Gypsum soils occur widely in arid and semi-arid environments where high rates of evaporation and low precipitation occur. Levels of salinity are estimated through determination of electrical conductivity and ion concentration, whereas SAR indicates risk of soil sodicity and effects of sodium on the physical and chemical nature of soil (Bony et al., 2025). Therefore, evaluation of the physical and chemical properties and fertility of gypsum soils is important for soil diagnosis, discrimination between study areas, and the determinants of soil properties and their susceptibility to degradation processes. In addition, results obtained from these studies can provide useful information for developing a database on soil characteristics in the study region, evaluation of the agricultural environmental potential, and establishment of a proper management and conservation strategy in order to counteract degradation and desertification impacts. This study derives its significance from the need to provide a comprehensive assessment of the physical and chemical properties of the soils in the study area, particularly salinity levels and their relationship to soil properties, land quality, and various land uses. The study's findings also help clarify the extent to which agricultural practices and fertilization affect certain physical and chemical properties of the soil, thereby aiding in the assessment of soil condition and fertility and supporting appropriate and sustainable land management. The study aims to determine the physical and chemical properties of the soil, assess salinity levels and their variation across study sites, and compare soil properties under different land-use types, including cropland, pasture, and fallow land, as well as to assess the impact of agricultural practices and fertilization on soil properties and to provide field data that can be used to evaluate soil quality and manage it more efficiently.

2. Materials and Methods

2.1 Sequence Data Acquisition and Curation

The study area is located in the Al-But'ama region, which lies between the districts of Baiji and Tikrit in Salah al-Din Governorate, central Iraq, on the highway connecting Baghdad and Mosul. The study area is located at the geographic coordinates 43.53229° east and 34.82801° north, which represent the longitude and latitude of the study's reference point, respectively. The study area is affected by a number of factors and processes related to desertification and land degradation; large parts of it are dominated by gypsum soils with low fertility and loose texture, and the area is also subject to the effects of wind erosion and dust storms. The natural vegetation is characterized by scattered shrubs and forage grasses; among the most important plant species found in the area are tartaria (*Schaginia aegyptiaca*), lagochium (*Lagonychium farctum*), mallow (*Malva parviflora* L.), radish (*Raphanus*), and thistles (*Alhagi mauronum*). The topography of the region is characterized by gentle undulations, with areas covered by shifting sands, particularly toward the western part of the region, as a result of sand encroachment and expansion from the sand dune areas in the Beiji district. Another part of the study area consists of natural pastures. During the 2025 growing season, 23 soil samples were collected from various locations within the study area; the locations were designated C1 through C23 on June 8, 2025. The selection of sampling sites was based on their field accessibility and their distribution along a transect, taking into account prevailing field conditions, local agricultural practices, and representation of variations in land use.

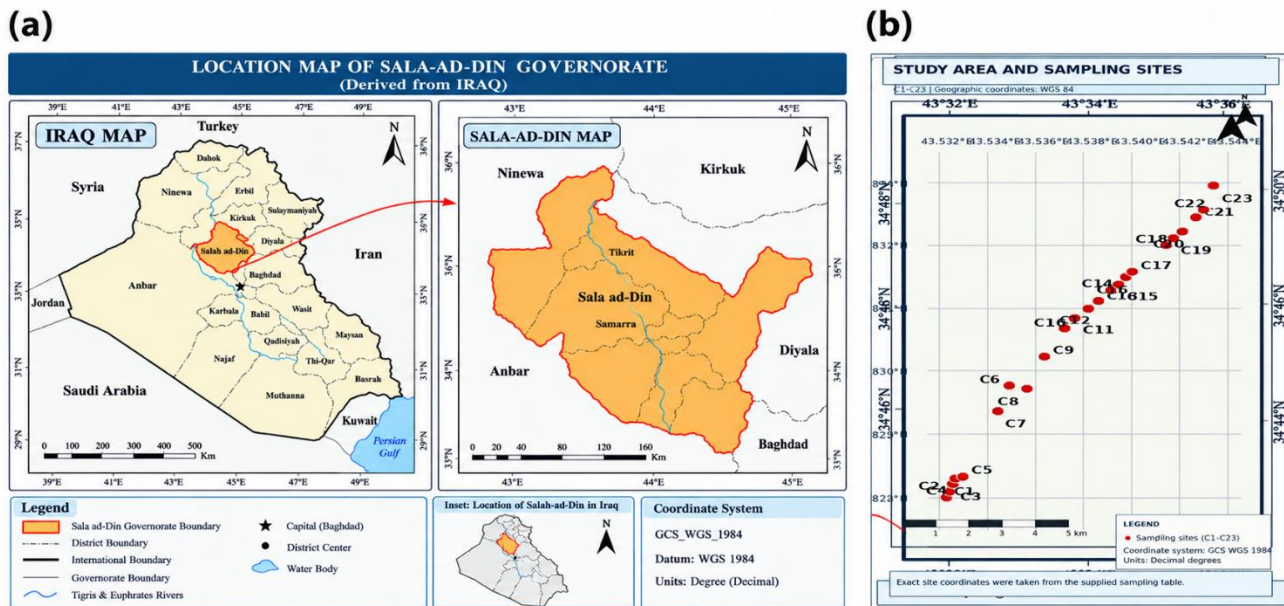


Figure 1. Map of the study area: (a) location of Salah al-Din Governorate within Iraq (b) study area and sampling sites.

The overall distribution of sampling sites spanned a distance ranging approximately from 1.1 to 5 kilometers, with varying distances between adjacent sites. The study area included fallow land,

cultivated land, and pastures, including areas where crops such as wheat and vegetables were grown. Several field visits were conducted to the study area, during which samples were collected from accessible sites based on field conditions and land use. Irrigation conditions also varied among sites; some agricultural lands relied on surface irrigation, while not all sites were irrigated.

Agricultural practices in the area included the use of chemical fertilizers, such as urea and diammonium phosphate (DAP). Soil samples were collected from the surface layer at depths ranging from 0 to 30 cm using a suitable hand-held soil sampler. The geographic locations of the sampling sites were determined using a GPS device, and the coordinates were recorded in decimal degrees. Soil samples were distributed in the appropriate dishes and dried in a dark room temperature for an appropriate period of time. Then the soil clods were dispersed, crushed, ground to an appropriate form and sifted by a 2-mm sieve. Identification label was put again on each sample in order to keep the sequence of the samples and make sure that the analysis of the samples is done according to their origin.

2.2 Physical Analyses

Soil Texture (Particle Size Distribution) — ((Soil Texture)

The texture was determined using the hydrometer method, as described by Gee and Bauder (1986).

2.3 Apparent Density

Apparent density was determined using the paraffin wax method according to Black (1965).

2.4 Soil Porosity

It is calculated using the relationship between apparent density and true density.

$$P = \left(1 - \frac{\rho_b}{\rho_s}\right) \times 100$$

P = Total porosity (%)

ρ_b = Bulk density (g/cm³)

ρ_s = Particle density (g/cm³)

- **Particle density = 2.65 g cm⁻³**

2.5 (MWD) Mean Weight Diameter

Dry Aggregate Size Distribution and Calculation of the Weighted Mean Diameter The weight distribution of the soil aggregates was determined using the method of McGuinness and Youker (1956), in which air-dried soil samples were dry-sieved to determine the weight percentages of the various aggregate size ranges. A 100-gram soil sample was weighed and then placed on a set of sieves arranged in descending order of mesh size, which included 9.4, 4.75, 2.36, 1.18, 0.500,

and 0.250 mm. The set of sieves was placed on a mechanical sieving machine, and dry sieving was conducted for 5 minutes under standardized conditions for all samples.

After the sieving process was completed, the amount of soil retained on each sieve was collected and weighed, and the relative weight of each size range was calculated as the ratio of the weight of soil retained in that range to the total weight of recovered soil. The representative diameter (X_i) for each size fraction was determined as the arithmetic mean of the upper and lower limits of that fraction. The Mean Weight Diameter (MWD) was calculated using the following equation:

$$MWD = \frac{\sum_{i=1}^n X_i W_i}{\sum_{i=1}^n W_i}$$

Here, MWD represents the weighted average diameter of the aggregate in millimeters (mm), X_i represents the representative diameter of size class i in millimeters, W_i represents the weight of soil retained in that same size class in grams (g), and n represents the number of size classes. The same amount of soil, the same sieve sizes, and the same sieving duration were used for all samples to ensure comparability across study sites.

2.6 Chemical Analyses

The soil pH and electrical conductivity (EC) were determined in an aqueous soil extract prepared at a soil-to-water ratio of 1:1, using the method described by Black (1965). To prepare the extract, 100 g of dry soil was weighed, and 100 mL of distilled water was added to achieve a 1:1 weight-to-volume ratio (100 g soil : 100 mL distilled water). The samples were then shaken thoroughly to ensure the soil mixed with the water and were left for 24 hours at a temperature of approximately 25 °C to allow the soil and aqueous solution to reach equilibrium. After the equilibration period, the electrical conductivity (EC) and pH of the extract were measured using a multifunctional device designed to measure both pH and EC. The measurements were taken after the instrument was set up and its stability was confirmed; electrical conductivity values were recorded in dS m^{-1} , while pH was recorded in pH units. The same soil-to-water ratio, equilibration period, and temperature were used for all samples to ensure uniform measurement conditions and the comparability of results across study sites.

2.7 Determination of Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) (Gypsum)

Gypsum was determined using the acetone precipitation method. The electrical conductivity (EC) was then measured after dissolving the precipitate in distilled water, and the percentage of gypsum was calculated as described in Richard's method (1954).

2.8 Determination of calcium carbonate (CaCO_3)

Calcium carbonate was determined by titration using 1 N hydrochloric acid (HCl), titrated with 1 N sodium hydroxide (NaOH), as described by (Ryan et al., 1996)

2.9 Determination of Organic Matter (O.M.)

Organic matter was determined using a potassium dichromate solution

No. 5 and titrated with ammonium ferrous sulfate, using a diphenylamine indicator, according to the method of (Tandon, 1998)

2.10 Dissolved Cations

- Calcium and Magnesium

Calcium and magnesium are determined in a 1:1 soil extract by titration with ethylenediaminetetraacetic acid (EDTA) (0.01), as described in the method by Richard.(1954)

- Potassium and Sodium

Potassium and sodium are determined in a 1:1 soil extract using a flame photometer, as described in the method by (Richards, 1954).

The sodium adsorption ratio (SAR) was calculated according to the following equation (Richards, 1954).

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{++} + Mg^{++}) / 2}}$$

2.11 Exchangeable Cations

The exchangeable cations in the soil—namely potassium (K^{+}), sodium (Na^{+}), calcium (Ca^{2+}), and magnesium (Mg^{2+})—were extracted using a 1N ammonium acetate (NH_4OAc) solution, according to the method described by Black (1965). Exchangeable calcium and magnesium were determined by volumetric titration using a standard EDTA solution, while exchangeable sodium and potassium were determined using a flame photometer. The results for exchangeable cations were expressed in centimoles of positive charge per kilogram of soil $cmol(+) kg^{-1}$

2.12 Total nitrogen

Total nitrogen in soil samples was determined using the Kjeldahl method, as described by Black (1965), with a Micro-Kjeldahl apparatus. The determination process involved digesting the soil samples with concentrated sulfuric acid in the presence of a catalyst to convert organic nitrogen and ammonium nitrogen into the quantifiable ammonium form. After digestion was complete, the digest was cooled and subjected to distillation in the Micro-Kjeldahl apparatus after the medium was made alkaline, at which point nitrogen was released as ammonia (NH_3). The resulting ammonia was collected in a suitable receiving solution and then quantified by titration using a standard solution. A blank test was conducted using the same reagents and following the same procedures without adding

a soil sample, in order to correct for the amount of reagent consumed due to the analytical background. The nitrogen content in the samples was calculated based on the difference between the volume of titrant consumed for the sample and the volume of titrant consumed in the blank test, taking into account the concentration of the titrant and the weight of the soil sample used in the analysis. The results were expressed in parts per million (ppm), which is numerically equivalent to mg N kg^{-1} of soil.

2.13 Available phosphorus

Available phosphorus in soil samples was determined using the Olsen method, with a 0.5 M sodium bicarbonate (NaHCO_3) solution adjusted to a pH of 8.5. A 2.5-gram sample of soil was taken, and 50 mL of the extraction solution was added to it at a soil-to-solution ratio of 1:20; the samples were then shaken for 30 minutes and filtered. Phosphorus in the filtrate was determined colorimetrically using ammonium molybdate and ascorbic acid, and the absorbance was measured with a spectrophotometer at a wavelength of 660 nanometers. The phosphorus concentration was calculated based on a standard curve, and the results were expressed in ppm. Available phosphorus was calculated based on its concentration in the extract, the extraction volume, the soil sample weight, and the dilution factor.

2.14 Dissolved Anions

Dissolved anions in the soil aqueous extract (soil-to-water ratio of 1:1) were determined; these included carbonates, bicarbonates, chlorides, and sulfates, according to the standard methods described by Richards (1954) and Black (1965).

2.15 Carbonates and Bicarbonates (CO_3^{2-} and HCO_3^-)

The concentrations of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions in the aqueous soil extract—prepared with a soil-to-water ratio of 1:1—were determined using the volumetric titration method according to Richards (1954). The titration was performed using a standard solution of hydrochloric acid (HCl), and phenolphthalein and methyl orange were used as indicators to determine the titration endpoints for carbonate and bicarbonate. Ion concentrations were calculated based on the volume and concentration of hydrochloric acid consumed, and the results were expressed meq L^{-1} .

2.16 Chlorides (Cl^-)

Chlorides (Cl^-) were determined in a 1:1 aqueous soil extract using the volumetric titration method according to Richards (1954), using a 0.005 N silver nitrate (AgNO_3) solution, with potassium chromate (K_2CrO_4) as the titration endpoint indicator. The concentration of chloride ions was calculated based on the volume and concentration of the silver nitrate solution consumed, and the results were expressed meq L^{-1} .

2.17 Sulfate (SO_4^{2-})

Sulfate ions (SO_4^{2-}) in the soil extract were determined according to the method described by Black (1965), based on the precipitation of sulfate as barium sulfate (BaSO_4) using barium chloride (BaCl_2). The amount of sulfate present in the extract was determined, and the results were expressed meq L^{-1} .

2.18 Statistical Analysis

The laboratory data ($n = 23$) were analyzed using Microsoft Excel 2016. Statistical analyses included calculations of the arithmetic mean, standard deviation, minimum and maximum values, and coefficient of variation (CV%). Correlation analysis was also performed using Pearson's correlation coefficient (r) and linear regression analysis, including the coefficient of determination (R^2), regression equations, p-values, and 95% confidence intervals. A statistical significance level of 0.05 was adopted, and P-values < 0.05 were considered statistically significant. A preliminary check was also conducted on the analysis assumptions and outliers. Given the possibility of spatial dependence among geographically close sites, this factor was taken into account as one of the study's limitations when interpreting the results. It should be noted that statistical correlation does not necessarily indicate a causal relationship.

3. Results and Discussion

3.1 Physical Properties

Size Distribution of Soil Particles

The results of laboratory analyses of soil particle size distribution, shown in Table (1), indicate a clear variation in the textural classes of surface soils across the study area. The textural classes ranged from sandy loam, loam, to sandy loam. In general, it is observed that the order of soil fractions in terms of their proportions was toward an increase in sand, followed by silt, and then clay at most study sites. This variation in soil texture can be attributed to the differing effects of the predominant soil-forming factors in the region, particularly the amount of rainfall, the type of natural vegetation cover, as well as erosion and sedimentation processes that contribute to the redistribution of soil components and their transport from one location to another. Furthermore, differences in the nature of the parent material are among the factors that directly influence the textural characteristics of the soils in the study area. In general, gypsum soils are characterized by textural differences between their surface and subsurface layers, depending on the nature of the parent material and its components—sand, silt, and clay—as well as the degree to which these components are mixed with the deposited materials.

Table (1) Physical Properties of Soils at the Study Sites

Sample	Coordinate	Soil particle size distribution	Texture class	Bulk density	Porosity
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	<i>X</i>	<i>Y</i>	Sand	Silt	Clay		Weighted mean diameter	
			g/kg				g.cm ⁻³	mm
C1	34.82801	43.53229	160	685	155	silt loam	1.40	1.78
C2	34.82809	43.53239	110	790	100	silt loam	1.47	2.78
C3	34.82821	43.53256	270	540	190	silt loam	1.32	1.63
C4	34.8283	43.53268	620	275	105	sandy loam	1.55	2.23
C5	34.82833	43.533	685	200	115	sandy loam	1.41	2.76
C6	34.82977	43.53491	320	535	145	silt loam	1.36	2.26
C7	34.82936	43.53443	350	460	190	Loam	1.46	2.00
C8	34.82971	43.53565	560	300	140	sandy loam	1.55	2.13
C9	34.83024	43.53638	375	375	250	Loam	1.36	2.24
C10	34.83068	43.53719	175	610	215	silt loam	1.42	2.12
C11	34.83085	43.53763	125	585	290	silty clay loam	1.40	1.98
C12	34.831	43.53819	275	465	260	Loam	1.19	1.97
C13	34.83112	43.5386	660	190	150	sandy loam	1.32	2.46
C14	34.8313	43.53914	385	485	130	Loam	1.47	2.06
C15	34.83138	43.53944	235	575	190	silt loam	1.33	2.14
C16	34.8315	43.53975	345	390	265	Loam	1.13	2.32
C17	34.83159	43.54002	160	685	155	silt loam	1.33	1.86
C18	34.83201	43.5414	450	410	140	Loam	1.25	1.89
C19	34.83212	43.5417	325	550	125	silt loam	1.55	2.16
C20	34.83222	43.54209	305	565	130	silt loam	1.53	2.15
C21	34.83245	43.54263	160	660	180	silt loam	1.55	2.31
C22	34.83258	43.54297	475	375	150	Loam	1.45	2.09
C23	34.83296	43.54339	535	295	170	sandy loam	1.32	2.35

Romero and Van Alphen (1971) noted this textural variation in gypsum soils, as their textural characteristics are largely related to the properties of the parent material and the materials that contributed to their formation . It is evident from the data in Table (1) that the sand fraction was predominant in most soil samples across the various study sites, followed by the silt fraction, and then the clay fraction. The sand fraction values ranged from (110–685) g•kg⁻¹. The high proportion of sand at most study sites can be explained by the increased content of gypsum crystals and gypsum in the soil, particularly since some of these particles are of a size approaching that of coarse sand, as indicated by the results of chemical analyses of the region's soils. Furthermore, the relationship between gypsum content and the sand fraction ratio may help explain the notable variation in this fraction's values among the study sites, which is consistent with the findings of Langford et al. (2016).

As for the silt fraction, its values ranged from (190–790) $\text{g}\cdot\text{kg}^{-1}$, and its content appears to be higher in some soil samples compared to others. This may be related to the nature of the parent material and the conditions to which it was exposed during weathering, transport, and deposition, as the silt content varies depending on the source of the soil-forming materials and the geomorphological processes affecting the region; this is consistent with the findings of (Rubinić et al, 2015). As for the clay fraction, its values ranged from (100–290) $\text{g}\cdot\text{kg}^{-1}$, and the results showed a low clay content in most of the soils in the study area. This may be related to the dry climatic conditions prevailing in the region and the accompanying reduction in weathering processes and the formation of clay minerals, as well as the scarcity of natural vegetation cover and low organic matter content. The high gypsum content at some study sites may also play a role in the low clay content, as there may be an inverse relationship between gypsum content and the clay fraction in some soils of the region, which is consistent with the findings of Shainberg et al. (1989). Based on the relative distribution of soil textural fractions, it was found that most study sites were characterized by sandy loam and loam textures, with limited variations at some sites where sandy loam texture was observed. This variation reflects differences in the nature of the soil-forming materials and the factors and processes that contributed to their formation and evolution within the study area.

3.2 Apparent Soil Density

The results presented in Table (1) indicate variation in the apparent density values of the soils in the study area, with values ranging from (1.13–1.55) $\text{g}\cdot\text{cm}^{-3}$. Some study sites recorded low bulk density values ranging from 1.13 to 1.32 $\text{g}\cdot\text{cm}^{-3}$. This variation can be attributed to differences in organic matter content and soil texture characteristics in the surface layer, as variations in soil components and the degree of particle aggregation affect bulk density values.

3.3 Soil Porosity

The results in Table (1) show that the total porosity values for the soils in the study area ranged from (41.51–57.36) %, with the majority of samples falling within the range of (50–57)%. The lowest porosity value recorded was approximately 41%. The variation in porosity values can be explained by differences in soil texture types and their content of various fractions, as porosity is directly related to the size distribution of soil particles. An increase in the proportion of coarse fractions leads to a decrease in total porosity, whereas an increase in fine fractions can contribute to higher porosity values, due to differences in pore distribution among soil particles. This result is consistent with the findings of Mola-Abasi et al. (2018) and Kenigsberg et al. (2020).

3.4 Mean Weight Diameter

Table (1) shows the Mean Weight Diameter values for soil aggregates in surface samples from the study area, measured after dry sieving; the values ranged from (1.55–2.78) mm. A variation in the weighted mean diameter values was observed among the different study sites; this variation may be related to differences in the nature of the dominant vegetation at each site, as well as the role of plant root systems in increasing the cohesion of soil particles and forming more cohesive aggregates. These values may also be influenced by plant species and the amounts of plant debris accumulated on the soil surface, as well as by the effect of organic matter resulting from the decomposition of residues and root exudates, which play a role in improving soil structure and influencing its physical properties. These results are consistent with those reported by (Oades and Tisdall, 1982).

3.5 Chemical Properties of Soils at the Study Sites

3.6 Soil pH

Soil pH is an important chemical property that directly and indirectly influences many of the soil's physical, chemical, and pedological characteristics. The results of laboratory analyses of surface soil samples from the study area, shown in Table (2), revealed variation in soil pH values, which ranged from 7.10 to 7.99. The high pH values at some study sites are attributed to the nature of the parent material, which consists mainly of limestone and gypsum, whose pH values range from 7.6 to 8.2; this is consistent with the findings of (Hartemink & Barrow, 2023). The other pH values were neutral to slightly alkaline, ranging from 7.4 to 7.7. This variation may be related to differences in certain soil properties among the study sites, particularly the content of gypsum, calcium carbonate, and organic matter, as well as differences in texture and the types of salts predominant in the soil.

3.7 Electrical Conductivity (EC)

The results presented in Table (2) show a clear variation in the electrical conductivity values of the soil in the study area, as some sites recorded relatively high values of (4.86), while values at other sites were around (2.14). Electrical conductivity was measured using an aqueous soil extract; the extract was prepared with a soil-to-water ratio of 1:1, and the samples were shaken for 24 hours at a temperature of approximately 25°C before measuring the extract's electrical conductivity.

Table (2) Chemical Properties of Soils at the Study Sites

Sample	PH	EC	O.M	CaCo ₃	CaSo ₄ .2Ho ₂
		(dS.m-1)			g·kg ⁻¹
C1	7.18	2.94	11.5	110	74.4
C2	7.17	2.99	12.7	110.5	78.3

C3	7.25	3.46	20.4	150	100.8
C4	7.47	3.91	15.4	200	104.3
C5	7.71	2.94	11.8	190.5	74.7
C6	7.79	3.03	17.2	140	73.5
C7	7.59	2.16	10.1	170.5	75.6
C8	7.86	2.85	16.1	150.5	89.1
C9	7.75	3.5	6.6	130	87.3
C10	7.23	2.75	4.3	130.5	78.2
C11	7.1	3.98	27.2	190	69.5
C12	7.77	2.84	12.5	140.5	60.3
C13	7.33	2.14	24.8	150.5	67.9
C14	7.99	3.39	9.3	160.5	143.3
C15	7.51	2.16	23.6	170.5	68.7
C16	7.66	3.08	9	140.5	66.1
C17	7.55	2.35	3.3	190	84.3
C18	7.4	2.73	10.7	170	76
C19	7.71	4.48	23.7	180	119.6
C20	7.74	4.86	9.8	150.5	125.7
C21	7.76	2.45	6.7	160	82.7
C22	7.68	3.04	8.2	210.5	65.2
C23	7.71	2.56	8.8	140.5	75.1

Abbreviations: pH = Hydrogen ion concentration; EC = Electrical Conductivity; O.M = Organic Matter; CaCO_3 = Calcium Carbonate; $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ = Calcium Sulfate Dihydrate (Gypsum).

The relatively high electrical conductivity values in some samples can be attributed to the dry climate prevailing in the study area, accompanied by high evaporation rates and frequent periods of soil drought, as well as irrigation and moisture management practices. Together, these factors lead to an increase in the concentration of dissolved salts in the soil solution and, consequently, higher electrical conductivity values, particularly as salts are transported and rise to the surface layers due to capillary action. These results indicate that electrical conductivity is an important and reliable indicator for assessing soil salinity levels and the extent of soil degradation and desertification. It is also evident that salinity distribution was not uniform across the study sites, as some samples recorded higher values than others, which may reflect differences in environmental conditions, soil characteristics, and the degree to which each site is affected by degradation and salinization processes (Dewangan et al., 2023).

3.8 Soil Organic Matter (O.M.) Content

The results in Table 2 show variation in organic matter content among the study sites, with values ranging from (3.3–27.2) g. kg⁻¹. Organic matter is an important component of soil due to its role in providing a food source for microorganisms and plant roots; various biological processes also contribute to its decomposition and conversion into simpler compounds. The low organic matter content in the soils of the study area is linked to the prevailing climatic conditions, characterized by high daily, seasonal, and annual temperatures, low rainfall, and high evaporation rates. These conditions also lead to increased salt accumulation in the soil, which negatively affects the density and growth of vegetation, thereby reducing the amount of plant residues—one of the primary sources of organic matter in the soil. Moisture content and temperature are among the key factors controlling the accumulation and decomposition of organic matter in the soil (Dregne, 1976), which is consistent with the prevailing environmental conditions in the study area. Furthermore, a decrease in organic matter content can affect a number of the soil's physical properties by reducing its water-holding capacity, weakening the cohesion of its fine particles, and degrading its structure, thereby increasing its susceptibility to drought and disintegration. Consequently, low organic matter content can be considered one of the contributing factors to the onset of degradation and desertification at the study sites (Voltr et al., 2021).

3.9 Gypsum Content in Soil (CaSO₄•2H₂O)

The results showed that the gypsum content in the soils of the study area ranged from (60.3–143.3) g•kg⁻¹, with variation in values among different sites. The high gypsum content in some soils of the region can be attributed to the nature of the parent material and the sedimentary materials that contributed to soil formation, particularly the sediments associated with the Makhoul mountain range located east of the study area, which may have supplied the region with gypsum-bearing materials. As for the lower gypsum content in some surface samples, this may be related to the greater exposure of these layers to various geomorphological factors and processes. Furthermore, surface layers are more exposed to rainwater, which may lead to the leaching of some of the gypsum and its migration from the surface horizons to the subsurface horizons, thereby reducing its content in the surface layer compared to some other horizons (Hundi et al., 2026).

3.10 Calcium Carbonate (CaCO₃) Content

The results in Table (2) show variation in calcium carbonate content among the study sites, with values ranging from (110–210.5) g•kg⁻¹. The results indicate an inverse relationship between the calcium carbonate and gypsum contents in some of the region's soils, as an increase in gypsum content may come at the expense of calcium carbonate content within the gypsum horizons. This is explained by the occurrence of decalcification, as well as gypsification, as these processes contribute to the

redistribution of soil components and the formation of gypsum horizons, leading to an increase in the gypsum content at the expense of other soil components, including calcium carbonate (Park et al., 2025).

3.11 Concentrations of Soluble Cations and Anions in the Soil Solution:

From the results obtained from the laboratory analysis indicated in Table (3), there was a presence of a number of dissolved cations and anions in the soil solution of the study area. These cations include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+), while the anions include bicarbonate (HCO_3^-), sulfate (SO_4^{2-}), and chloride (Cl^-). From the results obtained, there was a dominance of calcium ions (Ca^{2+}) as the cation with highest value followed by magnesium ions (Mg^{2+}) and then sodium ions (Na^+); potassium ions (K^+) had the lowest values as compared to other cations. This is due to the fact that there is a high concentration of calcium ions in the soil solution due to the nature of the parent material in the study area which is rich in calcareous and gypsum soils. With regard to magnesium ions (Mg^{2+}), this came second after calcium in terms of concentration, where their high values were observed in some study areas due to the existence of dolomite and some clay minerals such as palygorskite, as they play an important role in the formation of magnesium ions in the soil solution; this is according to (Neman and Singer, 2000). Sodium ion (Na^+) came third after calcium and magnesium; the presence of sodium ion in the soil solution may be attributed to the weathering and ion exchange process where they can be transferred to the soil solution; this is according to Hem (1989). For the potassium ion (K^+), it is worth noting that it had the lowest concentration in the samples from the study area compared to other ions. Its low concentration can be associated with the fact that potassium can be found in soil as a source of the element and its tendency to dissociate and enter the soil solution compared to other cations. For the anions, the results indicated that their concentrations were relatively low, except the chloride ion (Cl^-) which dominated among the anions.

Table 3: Concentrations of Soluble Cations and Anions in the Soil Solution:

Sample	Dissolved Positive Ions				Dissolved Negative Ions			
	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3	CL	SO_4^{2-}	SAR
	<i>meq L⁻¹</i>							
C1	12.73	3.22	1.14	1.46	2.4	7.8	2.86	0.404
C2	8.95	5.9	1.63	1.05	2.2	8.4	2.91	0.598
C3	10.04	4.32	0.48	1.26	2.8	5.4	2.92	0.179
C4	9.16	3.48	0.62	0.55	2.4	6	2.86	0.247
C5	8.57	3.41	0.34	1.06	2.6	4.6	2.86	0.139

C6	8.72	4.65	0.53	1.05	2.9	7.2	2.85	0.205
C7	10.16	4.74	0.65	0.93	4.8	4.3	2.87	0.238
C8	8.64	4.79	1.69	1.17	1.6	9.6	3.03	0.652
C9	11.03	6.43	0.54	0.57	3	6.4	3.01	0.183
C10	8.98	2.24	0.53	0.92	0.8	8.8	2.9	0.224
C11	10.64	2.37	1.76	1.07	1.6	8.4	2.8	0.690
C12	9.18	4.72	1.03	0.92	1.8	10	2.7	0.391
C13	14.46	3.82	0.69	0.18	1.2	10.4	2.78	0.228
C14	10.37	6.47	1.75	1.06	1	12.4	2.73	0.603
C15	8.48	2.33	1.46	1.05	0.8	8	2.79	0.628
C16	8.94	2.58	0.36	0.67	0.4	8.8	2.76	0.150
C17	8.91	5.66	1.09	0.55	1.4	8.4	2.98	0.404
C18	9.69	5.23	0.73	0.93	0.8	10	2.88	0.267
C19	9.52	3.85	1.05	0.44	0.4	12	2.92	0.406
C20	8.78	5.04	0.62	1.1	0.4	8	2.76	0.236
C21	11.74	2.18	1.3	0.64	1.4	12.4	2.96	0.493
C22	9.09	2.89	1.18	0.39	1.2	11.2	2.75	0.482
C23	10.86	5.13	0.87	0.66	1.6	8.4	2.87	0.308

Abbreviations: Ca^{2+} = Calcium; Mg^{2+} = Magnesium; Na^+ = Sodium; K^+ = Potassium; HCO_3^- = Bicarbonate;

Cl^- = Chloride; SO_4^{2-} = Sulfate; SAR = Sodium Adsorption Ratio.

The elevated concentration of some dissolved salts in the soils of the study area might imply that these soils are affected by varying degree of salinity which might be associated with the dry climate in the region as well as the process of accumulation of salts in the soil. The elevation of salt concentration is one of the important parameters which might suggest that some of the study sites experience degradation (Cole & Zhu, 1999).

3.12 Sodium Adsorption Ratio

However, the laboratory analysis results for the chemical characteristics (Table (3)) revealed that the sodium adsorption ratios (SAR) were low at all studied locations. According to researchers, SAR is the key indicator to evaluate the level of soil vulnerability to salinization; it varies between 0.139 meq L^{-1} and 0.690 meq L^{-1} at all the studied sites. All in all, the sodium adsorption ratio values were low at all study locations; this is a good indicator from an agronomical perspective because it indicates that there is no evident issue associated with the presence of excessive exchangeable sodium and the danger of sodicity at the studied soils. However, low sodium adsorption ratio does not exclude the danger of salinity at some study sites since soils may be highly saline in terms of the presence of dissolved salts while there is no danger of sodicity (Xie et al., 2024).

3.13 Soil Fertility Characteristics:

3.14 Total nitrogen

Total nitrogen is a crucial nutrient in soil, considering the importance of the same in maintaining soil fertility, increasing productivity and being essential for many functions performed by plants. It is evident from the analyses given in Table 4 below that there is variability in the amount of Total nitrogen in soils sampled in the research area, ranging between 11 and 46 ppm. The minimum value was observed in sample C17 (11 ppm), while the maximum value was recorded in sample C3 (46 ppm). There is variability in the amounts of nitrogen in different soils due to differences in the prevailing conditions in the research sites. In addition, losses of nitrogen through leaching can reduce the amount available to plants and therefore limit soil fertility. These observations agree with the results obtained by Men-gel (1985).

3.15 Available Phosphorus

Based on the data shown in Table 4, it is clear that the phosphorus available in the soils of the study area varied between 4.17 to 16.54 parts per million, with most soils having a low level of phosphorus availability. The above findings correspond with those of other researchers who studied available phosphorus in soils in eastern Iraq, whereby no high phosphorus available was found in the soil samples analyzed. From the outcomes of the experiment, it can be concluded that there is variation in the amount of available phosphorus among different land use sites, whereby soils under agricultural usage have more available phosphorus compared to soils that are not under agricultural usage. The presence of low amounts of available phosphorus, as well as the prevalence of soils that lack phosphorus, may be explained by the presence of features characteristic of arid and semi-arid areas, particularly in soils that are calcareous, owing to the nature of phosphorus availability that is dependent on its association with calcium and less tendency to remain available for plants. This is in line with the findings of Amara et al. (2015).

Table (4) Fertility Characteristics of the Soil at the Study Site

Sample	Total nitrogen (ppm)	Available Phosphorus (ppm)	Exchanged Cations			
			Ca+2	Mg+2	Na+	K+
			cmolc kg ⁻¹			
C1	29	7.87	6.16	2.05	1.50	0.44
C2	31	6.21	6.21	1.25	1.65	0.57
C3	46	16.28	6.08	2.00	1.89	0.72
C4	38	6.86	5.28	1.29	2.67	0.61

C5	36	5.3	5.10	2.12	2.85	0.12
C6	28	6.04	5.18	1.33	2.15	0.09
C7	20	5.73	6.00	3.50	2.95	0.14
C8	28	9.23	5.75	1.21	3.00	0.89
C9	16	5.16	6.15	1.19	2.58	0.78
C10	15	5.03	6.05	3.08	2.87	0.75
C11	28	16.54	7.22	2.82	3.96	0.78
C12	22	8.7	7.50	2.58	2.22	0.71
C13	41	16.44	7.27	2.55	2.69	0.63
C14	15	5.1	6.45	1.76	1.40	0.51
C15	36	12.25	6.15	1.43	2.81	0.45
C16	14	5.11	5.75	1.25	2.09	0.23
C17	11	4.17	5.50	1.23	3.72	0.29
C18	20	6.55	6.25	2.95	2.59	0.18
C19	37	11.62	7.20	2.45	4.05	0.16
C20	19	5.19	7.50	3.60	2.77	0.73
C21	18	5.15	6.55	2.50	2.92	0.15
C22	21	5.2	6.48	1.80	3.02	0.21
C23	21	4.28	5.54	1.28	3.25	0.20

Abbreviations: Ca^{2+} = Calcium; Mg^{2+} = Magnesium; Na^+ = Sodium; K^+ = Potassium.

3.16 Exchangeable Cations

As can be seen from the results of the analyses shown in Table 3, there exist differences in the concentration levels of exchangeable cations in soils of the study region. They include such elements as calcium, magnesium, sodium, and potassium.

3.17 Exchangeable calcium

According to the findings, there is a relatively high exchangeable calcium content in most of the soils sampled in the study area, with the value being between 5.1 to 7.5 centimoles per kilogram. The reason for this high level of exchangeable calcium content is because the parent material of these soils has a high level of calcium carbonate content.

3.18 Exchangeable Magnesium

The exchangeable magnesium concentration was not much spatially variable, varying between 1.19 and 3.60 centimoles per kilogram of soil. This variability could be attributed to the difference in the nature of the soil components, parent material, and magnesium-containing minerals in each of the soil samples.

3.19 Exchangeable Sodium

Values of exchangeable sodium were found to range from 1.4 to 4.05 cmol/kg, with variations seen between samples. High exchangeable sodium values at various sampling sites are due to high soil salinity levels, whereby the increased accumulation of salt in the soil increases the amount of certain cations, including sodium.

3.20 Exchangeable Potassium

In this case, exchangeable potassium was seen to have the lowest concentration of all the other exchangeable cations. The values ranged between 0.09 and 0.89 cmol/kg. Low exchangeable potassium concentration at some of the sites can be due to soil degradation as well as low fertilization in some of the agricultural sites which may prevent the loss of this element. Generally, it is evident that there are differences in the cation concentrations in the study sites. This can be due to different types of vegetation present in each of these sites as well as the degree of decomposition of the organic matter, among others.

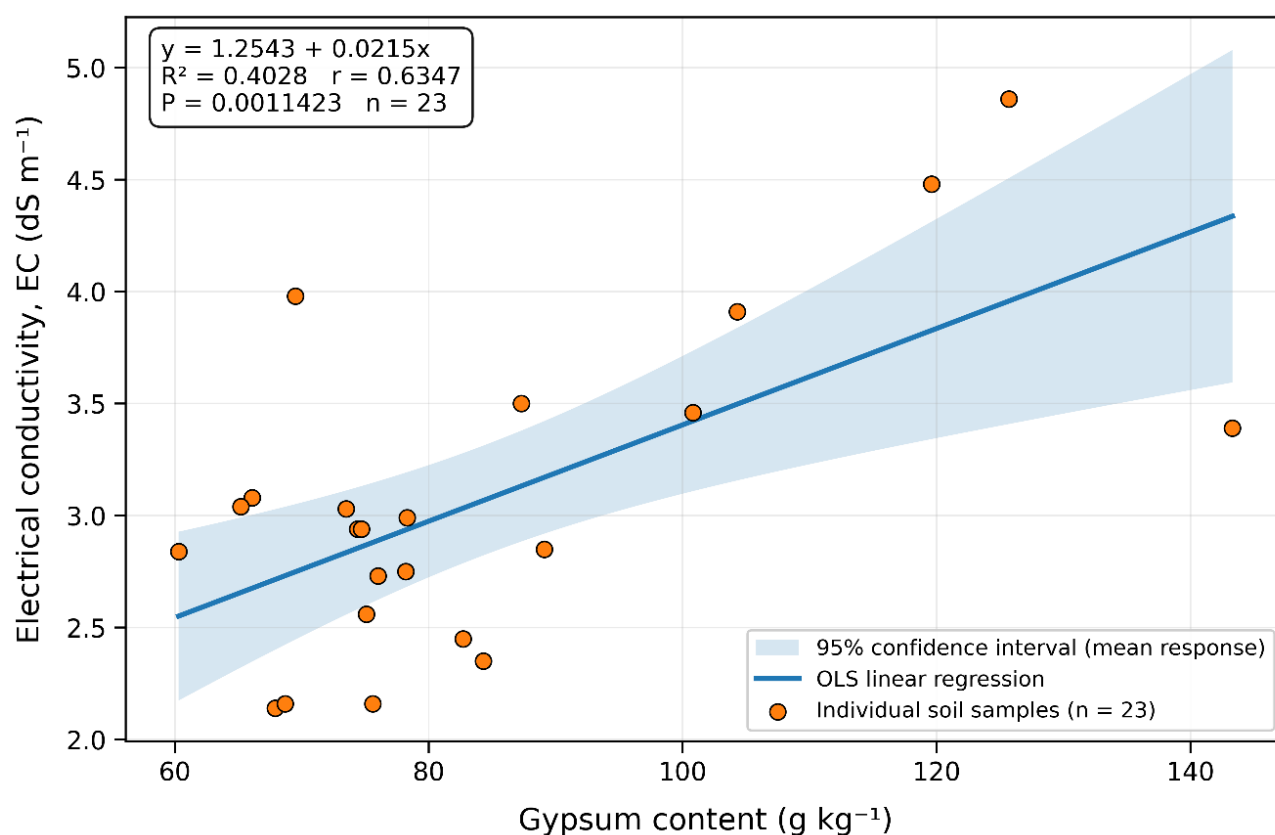


Figure 2. Relationship between gypsum content and electrical conductivity (EC).

Table(5) shows regression statistics

Regression statistics	Value
Slope	0.0215
Intercept	1.2543
R ²	0.4028
Pearson r	0.6347
p-value (slope)	0.0011
RMSE (dS m ⁻¹)	0.5647
95% CI slope	0.00962 to 0.03340
95% CI intercept	0.2220 to 2.2866
Regression equation	EC = 1.2543 + 0.0215 × Gypsum

Table (5) and Figure (2) above illustrate the regression relationship between gypsum levels and electrical conductivity, showing a positive correlation; We observe that electrical conductivity values increased with increasing gypsum levels, and the coefficient of determination was ($R^2 = 0.4028$), indicating that gypsum explains approximately 40% of the variation in electrical conductivity. On the other hand, the remaining variation can be attributed to other factors related to the soil's salinity and chemical properties, which is consistent with (Khorasani and Yazdi, 2011).

4. Conclusion

Considering the descriptive statistics for the gypsiferous soils sampled in Al-Bu Tu'mah, Tikrit, Salahuddin governorate (n=23), there is a clear indication that there is substantial spatial variability in the physicochemical characteristics of the soil sampled. The area has distinct textural differences in addition to having substantial gypsum content and EC levels. The observations are based on the pedogenic and environmental conditions of the sampled sites.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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