Research Article

Effect of Ionic Strength From Different Salt Sources on Iron Adsorption in Calcareous Soil

Awatif Hameed Dadoosh[1*], Kadhim Makki Naser[2] and Shireen Mudhafar Ali Alkhalil[3]

[1]Department of Soil Sciences and Water Resources, College of Agricultural Engineering Sciences, University of Baghdad, Baghdad, Iraq; [2]Department of Soil Sciences and Water Resources, College of Agricultural Engineering Sciences, University of Baghdad, Baghdad, Iraq; [3]Department of Desertification Combat, College of Agricultural Engineering Sciences, University of Baghdad, Baghdad, Iraq.

Abstract | This study was conducted to determine the effect of ionic strength from different saline sources on iron adsorption in a calcareous soil with a loam texture. This aim was achieved by performing a gentle equilibrium with an iron solution prepared from iron sulfate FeSO4 at concentrations of 0.5, 2.5, 5.0, 10.0, 20.0 and 30.0 micromol Fe mL-1 at a temperature of 298 K. Three ionic strengths were used, namely 0.1, 0.4 and 0.8 mol L^{-1}, of three types of salts, namely calcium chloride, magnesium chloride and sodium chloride. The linear single-plane Langmuir equation was used to describe the iron adsorption reactions in the study soil and to calculate the equation constants (Xm and k). The results indicated that adding iron to the soil significantly increased both soluble and adsorbed iron. The highest adsorption was observed in the $CaCl_2$ treatment at an ionic strength of 0.8 mol·L^{-1}, reaching 221.40 µmole Fe·g^{-1}. In contrast, soluble iron concentrations decreased as the ionic strength increased for all salts tested, while adsorption rose markedly, reaching 839.83 mol·L^{-1} in the same treatment. The order of adsorbed iron by salt was control > NaCl > $MgCl_2$ > $CaCl_2$. Additionally, the maximum adsorption capacity and the binding energy with soil particles increased, with binding energy ranking as follows $MgCl_2$ > $CaCl_2$ > NaCl > control. The bonding energy (k), we also found a positive and significant relationship between bond energy (k) and salt quality. The average bond energy for the different treatments was as follows: $MgCl_2$ = (0.404) > $CaCl_2$ (0.273) > NaCl = (0.192) > Control treatment (0.159)

Received | June 29, 2025; **Accepted** | October 01, 2025; **Published** | June 30, 2026
***Correspondence** | Awatif Hameed Dadoosh, Department of Soil Sciences and Water Resources, College of Agricultural Engineering Sciences, University of Baghdad, Baghdad, Iraq; **Email:** awatif.h@coagri.uobaghdad.edu.iq
Citation | Dadoosh, A.H., K.M. Naser and S.M.A. Alkhalil. 2026. Effect of ionic strength from different salt sources on iron adsorption in calcareous soil. *Pakistan Journal of Agricultural Research,* 39(2): 65-74.
DOI | https://dx.doi.org/10.17582/journal.pjar/2026/39.2.65.74
Keywords | Adsorption curves, Ionic strength, Calcareous soil, Maximum adsorption capacity of iron

Copyright: 2026 by the authors. Licensee ResearchersLinks Ltd, England, UK.
This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Introduction

Iron plays a fundamental role in plant growth and respiration. It is a component of many enzymes, including catalase, oxidases, and cytochrome peroxides, which play a key role in oxidation-reduction reactions in plant respiration. It is also a component of chlorophyll. Plants in arid and semi-

arid soils, particularly calcareous soils, suffer from widespread iron deficiency (Malkaouti and Tehrani, 2005). In the earth`s crust, Iron (Fe) is the fourth most abundant element (Salhi *et al*., 2022). However, Fe concentration in natural soil ranged from 7 to 42 g kg^{-1}(Wei *et al*., 2010). Iron is generally represented in primary minerals and several phyllosilicates in its ferrous (Fe II) state (Colombo *et al*., 2014).There are four main Fe groups in soil, including (i) Fe^{2+} in primary minerals, (ii) Fe^{3+} in secondary minerals (crystalized and (hydro) oxides Fe), (iii) exchangeable and soluble Fe, and (iv) Fe bounded to the organic matter in insoluble and soluble forms. However, calcareous soil is geologically present in arid and semi-arid regions because of minor leakage (Taalab *et al*., 2019), which covers about 30% of the earth`s surface, and low solubility of Fe reduces plant growth and reproduction (Ylivainio, 2010; Fayhaa *et al*., 2025; Mohammed *et al*., 2025). Iron is present in soil in two forms: divalent Fe^{+2} and trivalent Fe^{+3}. Plants can absorb and utilize iron in Fe^{+2} form, while Fe^{+3} form has low solubility and low activity, making it difficult for plant roots to absorb it. The active Iron content in soil is affected by several factors, including the degree of soil reaction, salts, and some ions (Priyadarshini *et al*., 2019). The salt content (ionic strength) affects plant growth and the solubility of iron, so the importance of this factor and its impact on plants should be taken into consideration. High calcium carbonate content and pH in calcareous soils limit iron solubility and availability by enhancing its adsorption and precipitation, while the increased ionic strength of salts enhances Iron adsorption in these soils by increasing the concentration of Iron cations in soil solution (Rasheed, 2023).

Chen and Barak (1982) have showed that in pH range of 7-9, $Fe(OH)_2$ and $Fe(OH)_3$ are the most abundant inorganic iron species in soil solution, which does not exceed 10 M Fe L^{-1}, but Kumar *et al*. (2017) reported that at high pH values, Iron is precipitated as insoluble, amorphous FeSiO4 by calcium carbonate, Iron and aluminum oxides, organic matter and clay minerals, which reduces the availability of Iron. Buehrer (2001) pointed out the ability of salts, especially mono salts such as Sodium chloride, to dissolve Calcium carbonate and release more calcium, which contributes to increasing its concentration in soil solution, which is reflected in the adsorption of Iron. Moharami and Jalali (2013) indicated that the highest Iron adsorption capacity was found when calcium was dominant in the equilibrium solution, indicating a high mobility of Calcium in soil, which contributed to increased Iron adsorption on adsorption sites. The opposite was true in case of Sodium dominance, and this is consistent with what Al-Tarbouli (2022) found, who indicated that increasing ionic strength in soil solution increases iron adsorption and precipitation.

Iron solubility decreases with increasing total Iron and soil pH due to adsorption of Iron by clay minerals, Iron and aluminum oxides, and the formation of ferrous minerals due to soil aeration, which reduces the amount of dissolved Iron (Mohiuddin *et al*., 2022). Jones (2020) reported. The most important soil characteristic is the pH, which reduces the solubility of iron in soil. Increasing pH of the soil leads to a decrease in Iron in soil solution; this is due to adsorption of Iron ions by calcium carbonate, active Calcium carbonate, Iron and Aluminum oxides, organic matter, and clay minerals. The amount of dissolved Iron in soil solution increases by decreasing soil pH (Kumar, *et al*., 2017 and Jones, 2020). Mohiuddin. *et al*. (2022) confirmed that Iron adsorption is affected by several factors, including the type of salts, degree of soil reaction, and the presence of organic matter. The accumulation of salts such as NaCl, CaCl2 in soil affects the charge balance on the surface of soil particles, which leads to ions present in salts (Na^{+}, Ca^{+2}) competing with Iron Ions (Fe^{+2}), Fe^{+3}) for adsorption sites, which reduces the process of iron adsorption on soil surface and thus increases the movement of Iron in soil solution or washes it out of root zone. Maximum adsorption values increase with the increase in electrical conductivity value because the increase in salt concentration leads to a shrinkage of the thickness of electrical double layer (Ali and Al-Qaisi, 2011), which increases the ability of Iron ions to get closer to the active adsorption sites at the surface and leads to an increase in Iron adsorption. Compression of electrical double layer gives a greater opportunity for adsorption of Iron ions present in equilibrium medium.

Element retention in soil is greatly affected by concentration of ions present in soil solution and ionic strength, so these conditions must be taken into account when studying the adsorption of elements in soil. Therefore, changing salt composition and ionic strength will affect the adsorption of elements (Miretzky *et al*., 2006). The aim of this research is to

study the effect of ionic strength from different salt sources on adsorption of Iron in calcareous soil.

Materials and Methods

Soil sample was taken from College of Agriculture, University of Baghdad (Al-Jaderia). Air dried, cleaned, and grinded with wood hummer and windowed through 2mm opening sieve and kept in plastic jars to be ready for lab analysis. Initial physical and chemical laboratory analysis were carried out according to methods mentioned in Black (1965), Page *et al.*, (1982). The soil analysis revealed EC $_{1:1}$ of 1.52 Ds m^{-1}, while the pH $_{1:1}$ 7.32. Organic matter content was 8.64 g kg^{-1}, and $CaCO_3$ 194.46 g kg^{-1}. The soil's cation exchange capacity reached 18.86 cmol+kg-1, Regarding soluble ions, Ca^{++} and Mg^{++} 3.85 , 2.60 mmol·L^{-1} respectively , whereas Na+ and K+ appeared in 0.81 , 0.62 mmol·L^{-1} CO3 ions were not detected, but HCO3 was measured at 1.35 mmol·L^{-1},Cl levels (10.90 mmol·L^{-1}) and SO4 0.86 mmol·L^{-1}. Available nitrogen, phosphorus, and potassium were 18.40, 7.11, and 67.53 mg·kg^{-1}, respectively. The physical composition of the soil consisted of 392 g·kg^{-1} sand, 402 g·kg^{-1} silt, and 206 g·kg^{-1} clay, classifying it as loam.

Iron adsorption was determined by taking 5 gm of dried and 2 mm opening sieved in a 100 ml test tube. 50 ml of salt solutions were added to each test tube containing Iron that prepared from $FeSO_4$(0.5 ,0.5,2.5,5.0, 10.0, 20.030.0, µmole Fe. ml^{-1}. Three levels of ionic strength (0.1, 0.4, 0.8 M) of $CaCl_2$, $MgCl_2$, and NaCl. Each treatment was replicated three times and designed under completely randomized design (CRD) of a factorial experiment. Test tubes were stoppered and shacked for 24 hours using quiet shaker to make sure that no destruction occur to soil particles in constant temperature (293 Kalvin) and after shaking, then the aliquot was centrifuged from precipitate at 3000 RPM for 10 minutes. Iron was then determined by atomic absorption apparatus (AAS) and according to method presented in Black (1965). Then Iron quantity adsorbed on soil particles was calculated for each treatment according to:

$$X= (A-C)V/S$$

Where:
X= adsorbed Iron on surface (µ mole.gm^{-1}soil)
A= added concentration of Iron (µ mole Fe.ml^{-1})
C= soluble Iron concentration in equilibrium solution (µ mole Fe.ml^{-1})
S= weight of soil sample
V= solution volume

Adsorbed/soluble Iron was described by the linear Langmuir equation of one layer as:

$$C/X = (1/k\ xm)+(C/Xm)$$

Where :
C= Iron concentration in equilibrium solution (µ mole Fe.ml^{-1})
X= adsorbed Iron (µ mole Fe.gm^{-1} soil.
Xm= constant representing the maximum adsorption capacity or highest limit of adsorption (µ moleFe. gm^{-1} soil).
k= a constant represents bonding energy of the adsorbed material (ml.gm^{-1}Fe) and it reflects the rate of adsorption in neutral status.

Graphing the linear relationship of C/X against C to get the slope 1/Xm from intercept 1/k xm we can get the constant k by dividing slope over intersect.

Results and Discussion

Results shown in Table 1 and 2 revealed that the soluble and adsorbed Iron quantity and is increasing significantly with the increase of added Iron to soil and that is parallel to the findings of Moharami and Jalali, 2013. In this study, they have indicated that there was an increase of adsorbed Iron with the increase of applied Iron to soil. Dissolved iron concentration increased from 0.04 to 0.21, 1.12, 3.46, 7.10 and 11.40 µmole L^{-1} when iron was added at levels of 0.5, 2.5, 5.0, 10.0, 20.00 and 30.00 µmol L^{-1} to calcium chloride salt at ionic strength 0.1 mole L^{-1} and so on for all added salts. This is consistent with what was found by Muhammad *et al.* (2025) who have showed an increase in soluble iron in the soil with increasing levels of added iron. Highest value of adsorbed Iron was 221.40 µ mole Fe.gm^{-1} soil in $CaCl_2$ treatment of 0.8 mole L^{-1} ionic strength at 30 µ mole Fe.ml^{-1} soil. Also, soluble Iron concentration is decreasing significantly with the increase of ionic strength of solution that represented by adding different salts, where soluble Iron concentration in equilibrium solution of $CaCl_2$ 3.88 µ mole Fe.ml^{-1} at 0.1 ionic strength and decreased to 3.16 and 2.59 µ mole Fe.ml^{-1} when ionic strength increases up to

Table 1: *Effect of added Iron on concentration of solubile, adsorbed Iron and percentage of adsorption of Iron in soil treated by $CaCl_2$ and NaCl*

Average	Concentration of added Fe to soil (µ mole.L-1)							Concentration of boron	Ionc strength µmole.L^{-1}))	Type of added salt
	30	20	10	5	2.5	0.5	0			
3.88 74.45 755.16	11.40 186.00 620.00	7.10 129.00 645.00	3.46 65.40 654.00	1.12 38.80 776.00	0.21 22.90 916.00	0.04 46.0 920.00	0 00	Solubile Fe (C) (µmole.ml^{-1}) Adsorbed Fe (X)(µmole.gm^{-1}) Percentage of Fe adsorption %)(adsorbed/ added))	0.1	$CaCl_2$
3.16 81.68 796.00	9.96 200.40 668.00	5.52 144.80 724.00	2.30 77.00 770.00	0.88 41.20 824.00	0.28 22.20 888.00	0.05 4.51 902.00	000	Solubile Fe (C) (µmole.ml^{-1})) Adsorbed Fe (X)(µmole.gm^{-1}) Percentage of Fe adsorption %)(adsorbed/ added))	0.4	
2.59 87.64 839.83	7.86 221.40 738.00	4.80 152.00 760.00	1.85 81.50 815.00	0.64 43.60 872.00	0.23 22.65 906.00	0.02 4.74 948.00	000	Solubile Fe (C) (µmole.ml^{-1})) Adsorbed Fe (X)(µmole.gm^{-1})) Percentage of Fe adsorption %)(adsorbed/ added))	0.8	
6.73 46.00 499.66	18.90 111.00 370.00	11.70 83.00 415.00	5.75 42.50 425.00	2.76 22.40 448.00	1.20 13.00 520.00	0.09 4.10 820.00	000	Solubile Fe (C) (µmole.ml^{-1}) Adsorbed Fe (X)(µmole.gm^{-1} Percentage of Fe adsorption %)(adsorbed/ added)	0.1	$MgCl_2$
5.97 53.60 571.13	16.73 132.70 442.33	10.97 90.30 451.50	4.97 50.30 503.00	2.13 28.70 574.00	0.96 15.40 616.00	0.08 4.20 840.00	000	Solubile Fe (C) (µmole.ml^{-1} Adsorbed Fe (X)(µmole.gm^{-1} Percentage of Fe adsorption %)(adsorbed/ added)	0.4	
5.23 61.08 626.47	15.17 148.30 494.33	9.11 108.90 544.50	4.28 58.00 580.00	2.00 30.00 600.00	0.80 17.00 680.00	0.07 4.30 860.00	000	Solubile Fe (C) (µmole.ml^{-1} Adsorbed Fe (X)(µmole.gm^{-1} Percentage of Fe adsorption %)(adsorbed/ added)	0.8	
9.84 14.91 232.58	27.03 29.70 99.00	17.93 20.70 103.50	8.13 18.70 187.00	3.95 10.50 210.00	1.76 7.40 296.00	0.25 2.50 500.00	000	Solubile Fe (C) (µmole.ml^{-1})) Adsorbed Fe (X)(µmole.gm^{-1}) Percentage of Fe adsorption %)(adsorbed/ added))		Control

LSD (Solubile Fe)= 0.16
LSD (Adsorbed Fe) = 3.39
LSD (Percentage of Fe adsorption) = 43.28

Table 2: *Effect of added Iron on concentration of solubile , adsorbed Iron and percentage of adsorption of Iron in soil treated by $MgCl_2$.*

Average	Concentration of added Fe to soil (µ mole.L-1)							Concentration of Iron	Ionc strength µ mole.L^{-1})	Type of added salt
	30	20	10	7.5	5	1	0			
7.53 37.95 453.33	21. 90 246.00 270.00	13.80 62.00 310.00	5.80 42.00 420.00	2.50 25.00 500.00	1.05 14.50 580.00	0.18 3.20 640.00	000	Solubile Fe (C) (µmole.ml^{-1})) Adsorbed Fe (X)(µmole.gm^{-1}) Percentage of Fe adsorption %) (adsorbed/ added)	0.1	NaCl
6.42 49.08 583.33	20.40 96.00 320.00	11.20 88.00 440.00	4.40 56.00 560.00	1.80 32.00 640.00	0.65 18.50 740.00	0.10 4.00 800.00	000	Solubile Fe (C) (µmole.ml^{-1})) Adsorbed Fe (X)(µmole.gm^{-1}) Percentage of Fe adsorption %) (adsorbed/ added)	0.4	
5.39 58.71 615.00	16.38 136.20 454.00	9.60 104.005 20.00	4.00 60.00 600.00	1.72 32.80 656.00	0.60 15.00 600.00	0.07 4.30 860.00	000	Solubile Fe (C) (µmole.ml^{-1})) Adsorbed Fe (X)(µmole.gm^{-1}) Percentage of Fe adsorption %) (adsorbed/ added)	0.8	
9.84 14.91 232.58	27.03 29.70 99.00	17.93 20.70 103.50	8.13 18.70 187.00	3.95 10.50 210.00	1.76 7.40 296.00	0.25 2.50 500.00	000	Solubile Fe (C) (µmole.ml^{-1}) Adsorbed Fe (X)(µmole.gm^{-1}) Percentage of Fe adsorption %) (adsorbed/ added))		Control

LSD (Solubile Fe)= 0.18
LSD (Adsorbed Fe) = 2.21
LSD (Percentage of Fe adsorption) = 41.74

0.4 and 0.8 mole.L^{-1} respectively and so on for other applied salts with different amounts. This is consistent with what was found by Moharami and Jalali (2013) who have indicated that the highest iron adsorption

capacity.

Calcium was dominant in the equilibrium solution, indicating a high mobility of calcium in the soil, which contributed to increased Iron adsorption on the adsorption sites. The opposite was true in the case of sodium dominance.

On the contrary, adsorbed Iron increases significantly with the increase of ionic strength of solution of all salts in different rates, where it reached 74.45 µ mole Fe.gm^{-1} at ionic strength 0.1 mole.L^{-1} $CaCl_2$ and increased to 81.68 and 87.64 µ mole Fe.ml^{-1} when ionic strength increases up to 0.4 and 0.8 mole.L^{-1} respectively and so on for other applied salts with different amounts. This is consistent with what was found by Al-Tarbouli (2022), who indicated that increasing the ionic strength in the soil solution increases the adsorption and precipitation of Iron.

In the meanwhile, a significant increase was occurred in adsorption percentage with the increase of ionic strength where it was 755.16 mole.L^{-1} at 0.1 mole.L^{-1} ionic strength of $CaCl_2$ and increased to 796.00 mole.L^{-1} and 839.83 mole.L^{-1} of both 0.4 and 0.8 mole.L^{-1} ionic strength respectively, and so on for other applied salts. This is consistent with what was indicated by Moharami and Jalali, 2013).

It was noticed that there was a decrease in adsorbed Iron percentage of applied with an increase of apples Iron and that could occur in the early hours of equilibrium that leads to busy adsorption location in soil and decreasing them, therefore, any increase of applied Iron causes imposing effect on Iron of equilibrium solution that results in diffusion Iron into inner crystal composition of clay minerals. These results corresponded with the same results of each. The variation in added salts has biggest impact in variation of added adsorbed Iron amount on soil surface, whereas highest adsorbed amount when adding $CaCl_2$ salt was 74.45, 81.68, 87.64 µmole Fe gm^{-1} soil to ionic strength 0.1, 0.4, 0.8 mole L^{-1} respectively, while adsorbed amount has been reduced significantly as well when NaCl added in a larger proportion. The values were 37.95, 49.08, 58.71 µmole Fe gm^{-1} soil to ionic strength above, while $MgCl_2$ salt the middle rank between both $CaCl_2$ and NaCl where adsorbed Iron amounts 46.00, 53.60, 61.08 µmole Fe gm^{-1} soil to ionic strength 0.1, 0.4, 0.8 mole L^{-1} respectively. We can arrange the amounts of adsorbed Iron as far as the different salts as follow: Control > NaCl > $MgCl_2$ > $CaCl_2$

As well as the amounts of adsorbed Iron with the three ionic strengths for salts as follow: Control (14.91) m.mole Fe gm^{-1} soil> (48.58) NaCl > (53.56) $MgCl_2$ > (81.21) $CaCl_2$.

These results correspond with Doula (2009) results where it was shown a highly significant distinction for $CaCl_2$ as compare with NaCl and for all levels of addition, and this can be resulted to the effect of salt type in increasing the value of pH. While Ali and Al-Qaisi (2012) have showed that the increasing in soil solution saltiness helps in increasing the pH where this will also increase adsorbed Iron on soil surface at all added concentration of Iron. This is consistent with what was indicated by Ali and Al-Qaisi (2012), who explained that the maximum adsorption values increase with the increase in electrical conductivity value because the increase in salt concentration leads to a shrinkage of thickness of electrical double layer, which increases the ability of Iron ions to get closer to the active adsorption sites at the surface and leads to an increase in Iron adsorption. Compression of the electrical double layer gives a greater opportunity for adsorption of Iron ions present in the equilibrium solution. Iron solubility decreases with increasing total iron and soil pH due to adsorption of iron by clay minerals, iron and aluminum oxides, and formation of ferrous minerals due to soil aeration, which reduces the amount of dissolved iron. (Chen *et al.*, 2009; Kumar, et,al. 2017 and Mohiuddin *et al.*, 2022). Chen and Shenker (2003) reported that the most important soil characteristic is pH, which reduces iron solubility in soil. Increasing the soil pH leads to a decrease in iron in the soil solution; this is due to the adsorption of iron ions by calcium carbonate, iron and aluminum oxides, organic matter, and clay minerals (Kumar *et al.*, 2017). The amount of dissolved iron in the soil solution increases by decreasing the soil pH (Colombo *et al.*, 2014 and Jones, 2020).

The increasing in adsorbed Iron when $CaCl_2$ added was followed by increasing in forming $CaCO_3$ in calcareous soils which will result in increasing the adsorbed Iron, where it works as a sinkhole for Iron in calcareous soils and holding it (Al-Azawy, 2012 and Alarazah and Alarazah, 2012), that was corresponded to what (Al-Azawy, 2012) found, where the large effect of calcium carbonate was shown in increasing

the adsorption of Iron in soil.

The availability and solubility of Iron are very limited due to some soil conditions, such as high pH, soil oxidation, and low organic matter in calcareous soils (Wei *et al*., 2010; Sotomayor *et al*., 2014 and Priyadarshini, 2019). Due to the high calcium carbonate content, active calcium carbonate content, and large surface area of clay, iron is the main factors controlling iron stabilization (Shehata, 2019). Iron is reduced in soil solution due to its adsorption on the surface of calcium carbonate, clay minerals, and aluminum/iron oxides (Kumar *et al*., 2017).

Also, adsorbed Iron quantity when $MgCl_2$ was applied came in second place which it is related to the effect of the applied Magnesium in increasing magnesium carbonate content that has the higher ability of increasing the adsorbed Iron in addition to increasing soil pH that contribute in increasing adsorbed Iron. Iron was much decreased when NaCl added and that could be related to the big role of this salt in dissolving Calcium Carbonate minerals and decreasing adsorption on them. that was parallel to what Buehrer (2018) found and showed that salts especially the mono salts such as NaCl have high ability to dissolve Calcium Carbonate minerals which leads to decrease the adsorbed Iron.

Rasheed 2023, has explained that it is in calcareous soils, Iron solubility is very limited because of the high pH and calcite values. The main results indicated that the soluble iron is negatively correlated with total Fe in soil and pH values but highly correlated with dissolved organic carbon and total dissolved carbon. From that, it is concluded that calcareous soils and soil organic matter has the main role in increasing Fe availability.

Linear Langmuir equation applied on results of tables 1 and 2 and graphing the concentration of soluble Iron (C) and concentration of soluble Iron (C) over adsorbed Iron (X), we can get a linear correlation due to this equation with high determination coefficient (R^2) which confirms the ability of using one layer Langmuir equation to describe the adsorption of Iron. Also results showed that there was a good similarity to explain adsorption behavior in different rates and high efficiency of this equation to describe the process of adsorption with a highly significant coefficient of determination (R^2) of all added salts from 0.637- 0.991 with an average 0.838 as shown in Figure 1-Figure 9.

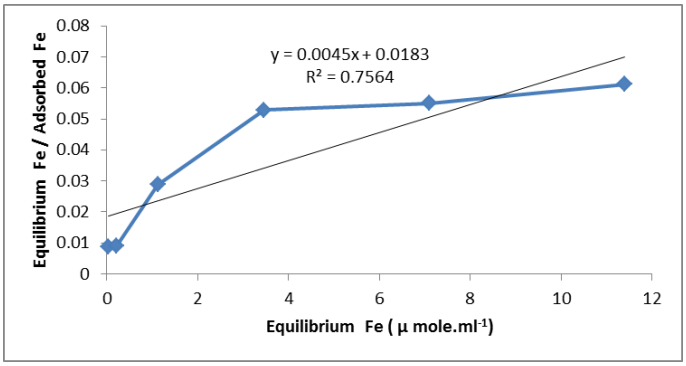

Figure 1: *Effect of added iron on langmuir equation constant at 0.1 CaCl2.*

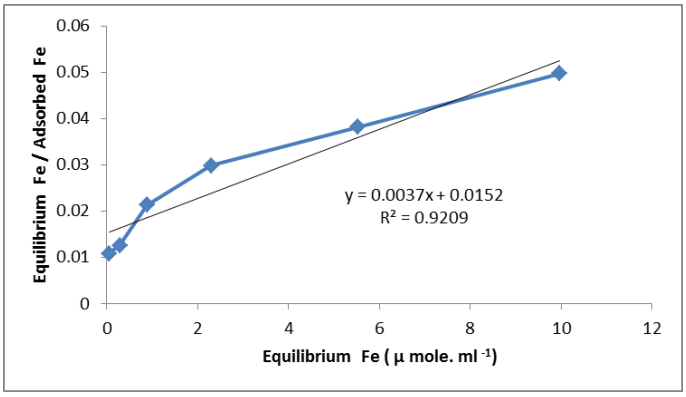

Figure 2: *Effect of added iron on langmuir equation constant at 0.4 M CaCl2.*

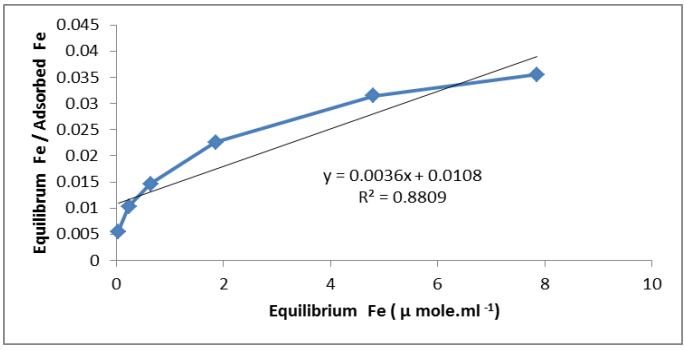

Figure 3: *Effect of added Iron on Langmuir equation constant at 0.8 M CaCl2.*

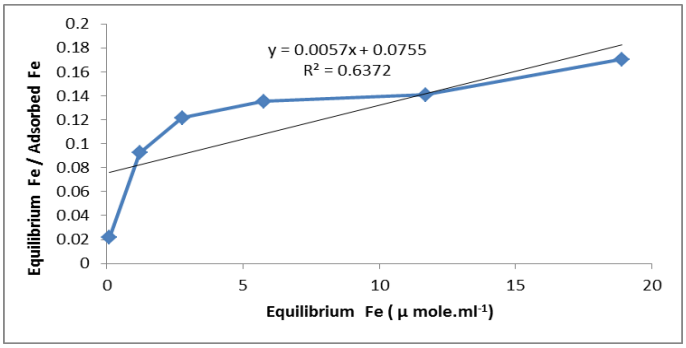

Figure 4: *Effect of added Iron on Langmuir equation constant at 0.1 MMgCl2.*

Table 3: *Effect of ionc strength for diriment salts on constants of langmuir equation and correlation coefficient of adsorbed equations of iron in soil.*

Correlation coefficient (R^2)	Bonding energy (k) (ml.μg^{-1} Fe)	Maximum adsorption (Xm) mg. μg^{-1} Fe))	Ionc strength μ mole.L^{-1}))	Type of added salt
0.7560.9200.880	0.2450.2430.333	222.222270.270277.777	0.10.40.8	$CaCl_2$
0.852	0.27	256.756		Average
0.6370.7580.718	0.0750.1021.035	175.438188.679230.095	0.10.40.8	$MgCl_2$
0.704	0.404	198.070		Average
0.9730.9910.918	0.1420.2720.162	102.040113.636178.571	0.10.40.8	NaCl
0.960	0.192	131.415	Average	
0.924	0.159	33.112	Control	
0.016	0.082	4.56	$LSD_{0.05}$	

Al-Tarbouli, 2022 has explained that both the Freundlich and Langmuir equations successfully described the iron adsorption process, but the Langmuir equation outperformed with the highest correlation values and lowest standard error values.

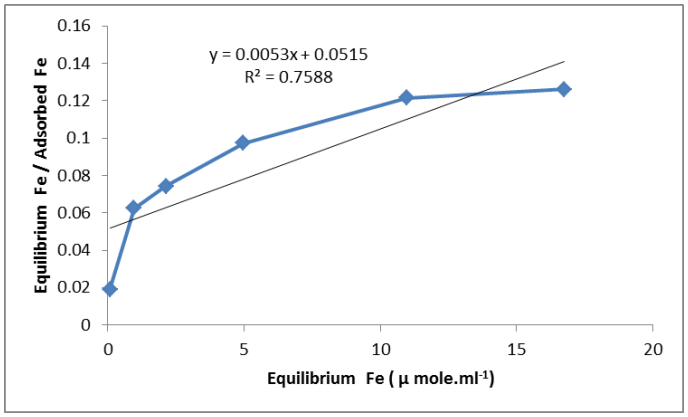

Figure 5: *Effect of added iron on langmuir equation constant at 0.4 M MgCl2.*

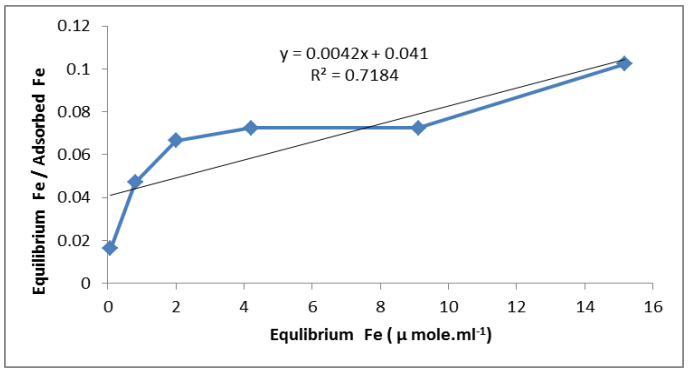

Figure 6: *Effect of added Iron on Langmuir equation constant at 0.8 M MgCl2.*

Constants of Langmuir equation was calculated from the figures, where Xm that represents the maximum range of adsorption or maximum adsorption capacity, and k that represents the bonding energy of Iron with soil particles surfaces which is shown in Table 3. this table showed that the increase of maximum adsorption capacity and bonding energy with soil particles for different salts, where Xm has increased in $CaCl_2$ treatment from 222.22 to 270.27 and 277.77 mg Fe.kg^{-1} soil for the ionic

strength 0.1, 0.4, and 0.8 mole.L^{-1} respectively, while it was increased from 175.43 to 188.76 and 230.09 mg Fe.kg^{-1} soil in magnesium chloride treatment of the 0.1, 0.4, 0.8 mole.L^{-1} ionic strength solutions. Also, for sodium chloride treatment the maximum adsorption capacity has increased from 102.04 to 113.63 and 178.57 mg Fe.kg^{-1} soil of the same ionic strength mentioned above. while it was 33.11 mg Fe.kg^{-1} soil in control treatment. while controlling among salts treatments we found that there was a significant difference where $CaCl_2$ might exceed and $MgCl_2$, then NaCl where the average of the maximum adsorption capacity of these treatments 256.75, 198.07, 131.41 mg Fe.kg^{-1} respectively when compared to control treatment at 33.11 mg Fe.kg^{-1}.

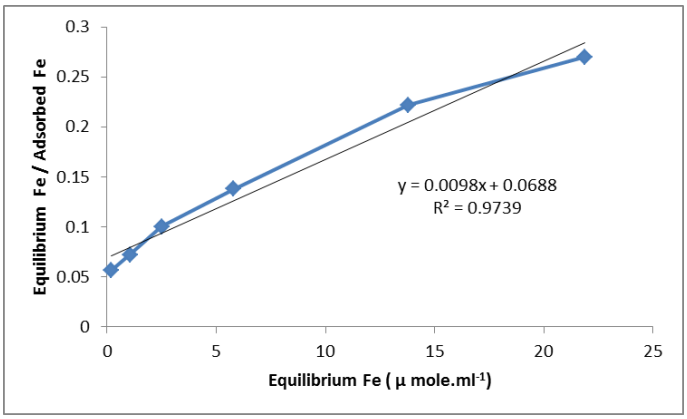

Figure 7: *Effect of added Iron on Langmuir equation constant at 0.1 M NaCl.*

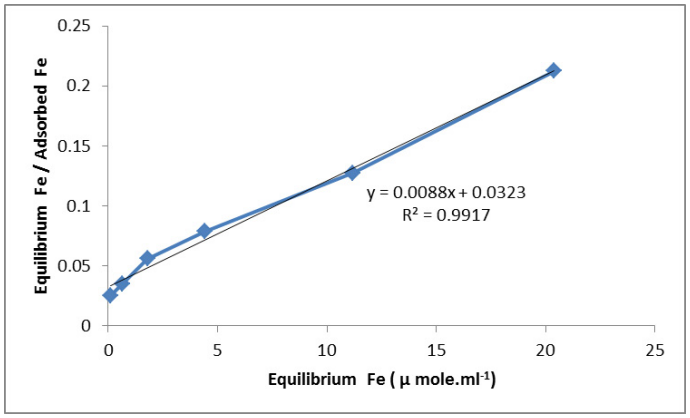

Figure 8: *Effect of added iron on langmuir equation constant at 0.4 M NaCl.*

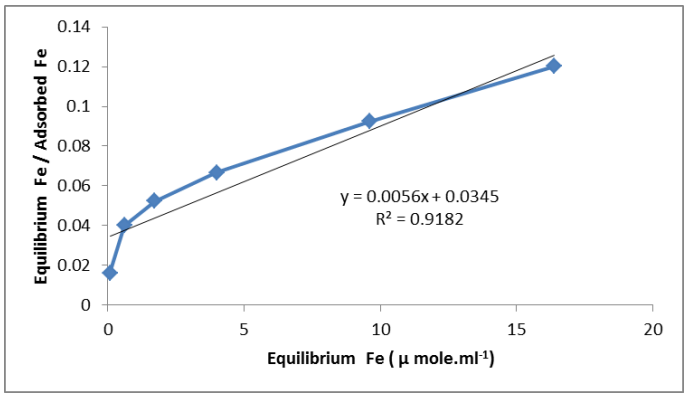

Figure 9: *Effect of added iron on langmuir equation constant at 0.8 M NaCl.*

Doula (2009) has explained that Iron adsorption increases in the presence of calcium ions, then magnesium, and finally sodium ions in the equilibrium solution. The bonding energy (k), we also found a positive and significant relationship between bond energy (k) and salt quality, as it was 0.273 µg-1 Fe in $CaCl_2$, increased significantly to 0.404 ml µg-1 Fe in $MgCl_2$, and decreased to 0.192 ml µg-1 Fe in NaCl, while it was 0.159 ml µg-1 Fe in the control treatment.

When comparing the different salt treatments, we found significant differences, with Magnesium chloride significantly outperforming Calcium chloride, followed by Sodium chloride, and finally the control treatment.

The average bond energy for the different treatments was as follows:

MgCl2 = (0.404) > CaCl2 (0.273) > NaCl = (0.192) > Control treatment (0.159)

In general, the results showed high values of maximum adsorption capacity (Xm), averaging 195.413 $mg.kg^{-1}$ of the total treatments, and a low binding energy, averaging 0.289 mg/1Fe. This could be related to the high content of carbonate minerals in the soil These results were in line with what was shown by (Al-Tarbouli, 2022) regarding adsorption sites, especially on the surfaces of carbonate minerals in the soil, where they studied a high maximum adsorption capacity with low binding energy when they studied iron adsorption in calcareous soils in northern Iraq. These results were also in line with Kumar, et,al. (2017), where they showed that iron binding energy was low in soil, when they studied calcareous soils using the single-layer Langmuir equation. These results are also consistent with what was indicated by Jones, (2020). when they studied iron absorption in calcareous soil, where they found an increase in the maximum absorption capacity.

Conclusions

This study investigates the effect of different salts and their ionic strengths on iron adsorption in calcareous loam soil. The results show that increasing ionic strength enhances iron retention by the soil while reducing its concentration in the solution. Among the salts tested, calcium chloride had the strongest effect in promoting iron adsorption, while magnesium chloride showed the highest binding energy with soil particles. The type of salt significantly influenced both the adsorption capacity and the strength of iron-soil interactions. These findings highlight the role of ionic composition in controlling iron mobility and availability in soil, with important implications for soil fertility and nutrient management.

Acknowledgements

The authors sincerely thank the University of Baghdad, College of Agricultural Engineering Sciences, and the University of Baghdad, College of Science, Department of Chemistry, for their support in providing laboratory facilities for this research.

Novelty Statement

This study uniquely reveals how different salts and their ionic strengths distinctly influence iron adsorption and soil–iron interactions in calcareous loam soils, providing new insights for soil fertility and

nutrient management.

Author's Contributions

Awatif Hameed Dadoosh, Kadhim Makki Naser and Shireen Mudhafar Ali Alkhalil: Contributed equally to this work and approved the final manuscript.

Generative ai and ai-assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of Interest

The authors declare that they have no conflicts of interest.

References

Al-Azawy, K.M.N. 2012. Effect of kind and concentration of salts and organic matter on electrical conductivity and soil reaction under leaching conditions. The Iraqi J. Agric.Sci., 43(3): 42-51

Al-Azawy, K.M.N and A.A.A. Alarazah. 2012. Studding chemical characteristics forsome wells in College of Agriculture ,University of Baghdad and asses its suitability for agriculture and Humanpurposes.The Iraqi J. Agric. Sci., 43(6): 59-70.

Ali, N.E.-D.S. and Al-Qaisi, S. Jalab. 2012. Soil Chemistry (translated), Ministry of Higher Education and Scientific Research, Department of Soil Sciences and Water Resources, College of Agriculture, University of Baghdad. Edited by Carson Sposito (2008), Second Edition.

Al-Tarbouli, N.H.Y. 2022. Adsorption and physicochemical release of iron ions in soils with different content of Calcium Carbonate and Calcium Sulfate Tikrit Journal for Agricultural Sciences. 22(3):731-741. https://doi.org/10.25130/tjas.22.3.16.

Black, C.A., D.D. Evans, L.E. Ensminger, J.L. White and F.E. Clark. 1965. (eds). Methods of soil analysis. Part 1 pp.545-566 American Society of Agronomy. Madison Wisconsin. USA.

Buehrer, T.F. 2001. Evaluation of Phosphorus Sources Soil types. J. Tech. Bull., 3(3): 42-58.

Chen, Y. and P. Barak. 1982. Iron nutrition of plants in calcareous soils. Advan. Agron., 35: 217-240. https://doi.org/10.1016/S0065-2113(08)60326-0

Chen, W., L. Li, A.C. Chang, L. Wu, R.L. Chaney, R. Smith, and H. Ajwa. 2009. Characterizing the solid–solution partitioning coefficient and plant uptake factor of As, Cd, and Pb in California croplands. Agric. Ecosys. Environ., 129(1-3): 212-220. https://doi.org/10.1016/j.agee.2008.09.001

Chen, Y., and Shenker, M. 2003. Agronomic approaches for increasing iron availability to food crops. Impacts of agriculture on human health and nutrition. Encycloped. Life Support Sys., (EOLSS), UNESCO, Oxford.

Colombo, C., G. Palumbo, J.Z. He, R. Pinton, and S. Cesco. 2014. Review on iron availability in soil: interaction of Fe minerals, plants, and microbes. J. soils sediment., 14(3: 538-548. https://doi.org/10.1007/s11368-013-0814-z

Doula, M.K. 2009. Simultaneous removal of Cu, Mn and Zn from drinking water with the use of clinoptilolite and its Fe-modified form. Water Res., 43(15): 3659–3672. https://doi.org/10.1016/j.watres.2009.05.037

Fayhaa M.N., H.T. Ibrahim, R.A.A. Alsahoo, I.A. Jihad, R.M.A.Z. Qais. 2025. oRGINAL article. J. Anim. Health Prod., 13(s1): 39–48. https://dx.doi.org/10.17582/journal.jahp/2024/13.s1.39.48

Hochmuth, G., T. Nell, J. Sartain, J.B. Unruh, C. Martinez, L. Trenholm, and J. Cisar. 2009. Urban Water Quality and Fertilizer Ordinances: Avoiding Unintended Consequences: A Rev. Scient. Litera.: SL 283/SS496, rev. 1/2011. EDIS: 2009(2). https://doi.org/10.32473/edis-ss496-2011

Jones, J.D. 2020. Iron availability and management considerations: A 4R approach. Crop. Soil., 53(2): 32-37. https://doi.org/10.1002/crso.2001

Kumar, M.B., C.T. Subbarayappa, and V. Ramamurthy, 2017. Distribution of available (DTPA-extractable) zinc and iron and their relationship with some soil properties in rice soils of Chamarajanagar district, Karnataka, India. Int. J. Curr. Microbiol. App. Sci., 6(5): 1423-1428. https://doi.org/10.20546/ijcmas.2017.605.155

Malakouti, M.J., and M.M. Tehrani. 2005. Micronutrient role in increasing yield and

improving the quality of agricultural products (1st ed.). Tarbiat Modarres University Press, Tehran, Iran.

Miretzky, P.X., M. Coles, and C. Alejandro, 2006. Experimental Zn (II) retention in a sandy loam soil by very small columns. Chemospher., 65(2006): 2082–2089. https://doi.org/10.1016/j.chemosphere.2006.06.047

Moharami, Somayeh and Jalali, Mohse. 2013. Effects of cations and anions on iron and manganese sorption and desorption capacity in calcareous soils from Iran. Environ. Earth Sci., (2013) 68: 847–858 https://10.1007/s12665-012-1787-8 .

Mohammad, I.Q., K.M. Naser, and M.M. Odeh. 2025. The role of adding humic acid and iron on availability of iron and macronutrient (NPK) In A calcareous soil planted with Wheat (Triticum Aestivum L.). Int. J. Appl. Sci. Technol., 7(1) March 2025.

Mohiuddin, M., M. Irshad, S. Sher, F. Hayat, A. Ashraf, S. Masood, ... and M. Waseem. 2022. Relationship of Selected Soil Properties with the Micronutrients in Salt-Affected Soils. Land., 11(6): 845. https://doi.org/10.3390/land11060845

Mohammed, M.D., T.K. Karyagdi, A.M. Qneed, I.A. Jihad, Q.R. Lahhob, M. Mudhafar, H.A. Alsailawi, & A.A. Ayada. 2025. Molecular characterization and zoonotic potential of giardia species in livestock with respect to their transmission dynamics and host adaptation. J. Anim. Health Prod., 13(s1): 411–421. https://doi.org/https://dx.doi.org/10.17582/journal.jahp/2025/13.s1.411.421

Page, A.L., R.H. Miller and D. R. keeney. 1982. Method of soil analysis, part 2, 2nd Agron. Madison Wisconsin, U.S.A.

Priyadarshini, P., T. Chitdeshwari, and C. Sudhalakshmi. 2019. A iron availability in calcareous and non calcareous soils as influenced by various sources and levels of iron. Madras Agric. J., 106. https://10.29321/MAJ2019.000265

Rasheed, M.S. 2023. Solubility of Iron (Fe II) in the Long-Term Vegetable Growing in Calcareous Soils. Passer J., 5(1): 103-109. www.garmian.edu.krd.

Salhi, K., H. Hajlaoui, and A. Krouma. 2022. Genotypic differences in the response of durum wheat (Triticum durum Desf.) to lime-induced iron chlorosis. Plant Direct., 6(1): e377. https://doi.org/10.1002/pld3.377

Shehata, S.M. 2019. Humic Acid Influence on Chemically Extractable forms of Iron and Manganese in some Calcareous Soils. J. Soil Sci. Agric. Engineer., 10(9): 517-525. https://doi.org/10.21608/jssae.2019.62560

Sotomayor, C., R. Ruiz, and J. Castro. 2014. Growth, yield and iron deficiency tolerance level of six peach rootstocks grown on calcareous soil. Ciencia e investigación agrarian., 41(3): 403-409. https://10.4067/S0718-16202014000300013

Taalab, A.S., G.W. Ageeb, H.S. Siam, and S.A. Mahmoud. 2019. Some Characteristics of Calcareous soils. A review AS Taalab1, GW Ageeb2, Hanan S. Siam1 and Safaa A. Mahmoud1. Middle East J., 8(1): 96-105. ID: MEJAR2019-8(1)-96-105 .

Wei, X., M. Shao, J. Zhuang, and R. Horton. 2010. Soil iron fractionation and availability at selected landscape positions in a loessial gully region of northwestern China. Soil Sci. Plant Nutrit., 56(4): 617-626. https://dx.doi.org/10.1111/j.1747-0765.2010.00497.x

Ylivainio, K. 2010. Effects of iron (III) chelates on the solubility of heavy metals in calcareous soils. Environ. Pollut., 158(10): 3194-3200. https://doi.org/10.1016/j.envpol.2010.07.004