Research Article

Effect of Zeolite Addition on Infiltration Rate and Saturated Hydraulic Conductivity in Gypsum Soil

Roaa Hameed Abed* and Hiba Abdullah Kareem

Department of Soil Sciences and Water Resources, College of Agriculture, Tikrit University, Al-Qadissiya District, Tikrit, Salah Al-Din Governorate, 34001, Iraq.

Abstract | The addition of zeolite has shown promise in improving soil physical properties, particularly in enhancing water movement through soil. Gypsum soil is a type of soil that contains a high percentage of the mineral gypsum (hydrated calcium sulfate CaSO42H2O) Reducing the percentage of gypsum in the soil is necessary to reduce soil problems, but increasing the percentage of gypsum by more than 3% causes problems for the soil and plants, and then it needs treatment and reclamation. This study investigates the effect of zeolite on the infiltration rate and saturated hydraulic conductivity in gypsum soils. An experiment was conducted in the laboratories of the Department of Soil Sciences and Water Resources, College of Agriculture, Tikrit University for the period 10/1/2022-10/1/2023 to demonstrate the extent of the effect of adding one of the soil improvers, which is the mineral zeolite, on infiltration ratr and some of the hydraulic properties of gypsum soils known for their weak structure, high apparent density, and low porosity, as the crust that affects the movement of water in it and the weak rates of evaporation and water conductivity. Three sites in their gypsum content were selected from Tikrit University (S1, S2, S3). Its content was gypsum (22.27, 13.29, and 25.60%), respectively. Zeolite was added at four addition levels (0%, 1%, 2%, and 3%) Symbolize them with the symbol (Z1, Z2, Z3, Z4), respectively. incubated in soil for 60 days, with additional water and daily soil turning. Laboratory measurements were conducted and the results showed the clear effect of zeolite mineral in improving the rates of leaching, as the value of leaching reached (5.83) cm/hour without addition, as it increased to (6.63) $cm.h^{-1}$ at the level of 3% addition for soil S1 with a low gypsum ratio. The same is the case for water conductivity, as it reached (4.80) $cm.h^{-1}$ without addition and increased (6.27) $cm.h^{-1}$ at the level of 3% addition for soil S1 with a low gypsum ratio.

Received | March 10, 2025; **Accepted** | May 31, 2025; **Published** | April 26, 2025
***Correspondence** | Roaa Hameed Abed, Department of Soil Sciences and Water Resources, College of Agriculture, Tikrit University, Al-Qadissiya District, Tikrit, Salah Al-Din Governorate, 34001, Iraq; **Email:** roaa.h.a514@st.tu.edu.iq
Citation | Abed, R.H. and H.A. Kareem. 2025. Effect of zeolite addition on infiltration rate and saturated hydraulic conductivity in gypsum soil. *Pakistan Journal of Agricultural Research,* 38(1): 85-91.
DOI | https://dx.doi.org/10.17582/journal.pjar/2025/38.1.85.91
Keywords | Gypsum soil, Zeolite, Saturated hydraulic conductivity, Infiltration rate

Introduction

Gypsiferous soils are those that contain more than 3% gypsum in the horizons that influence the effective root zone, The global extent of gypsiferous lands exceeds 850,000 km^2, with Iraq having approximately 88,000 km^2 of such soils, These soils suffer from a shallow surface horizon, insufficient for the growth and development of plant roots. Additionally, the high solubility of gypsum contributes to soil collapse and subsidence (Mahmoud and Ismaeal, 2024). Gypsum also influences the soil's physical, chemical, and fertility properties, often leading to degradation. Generally, gypsiferous soils exhibit weak, friable structures, limited water retention capacity, and the formation of surface crusts (Farhan *et al*., 2024).

Soil amendments are natural or synthetic materials used to improve one or more soil properties, facilitating the movement of water and air, as well as plant growth and development, these amendments alter the pore distribution in the soil, leading to changes in its structural properties, which then impact water movement, increase water retention capacity, reduce surface crust formation, and minimize wind erosion. Moreover, they enhance soil stability and reduce resistance to tillage, thereby increasing aggregate stability and the availability of stored water, that adding conditioners to the soil improves its physical properties (Jafaar *et al*., 2023; Javaid *et al*., 2024; Hamid, 2025).

Zeolite is a naturally occurring or synthetically produced mineral formed through the alteration of silicon-rich volcanic rocks in the presence of seawater under alkaline conditions and suitable temperatures (Khaleque *et al*., 2020). There are 167 synthetic and 48 natural types of zeolites, both sharing similar characteristics in terms of activity, crystalline structure, and high porosity. However, they differ in pore size and impurities, with synthetic zeolites having larger pores, making them more effective for absorption and ion exchange, Zeolites possess a high cation-exchange capacity, allowing them to efficiently retain and release nutrients. Natural zeolites are widely used to improve soil physical properties, particularly in nutrient-poor sandy soils. Their application as natural soil amendments enhances water use efficiency by increasing soil water retention and storage capacity (Hu *et al*., 2021).

Infiltration is the process by which water enters the soil through its surface and moves downward. It is one of the most critical properties in designing surface irrigation systems. Infiltration occurs as a function of soil conductivity and the hydraulic gradient at the soil surface (Zhang *et al*., 2020). Over time, infiltration rates decline due to the reduction in hydraulic gradient, which drives water movement. Other contributing factors include soil structural degradation, soil particle migration leading to pore clogging, air entrapment, and pore blockage caused by dispersed soil particles exerting counterpressure on water movement (Al-Juboori *et al*., 2023).

An increase in gypsum content can enhance gypsum dissolution due to the greater affinity between water and gypsum, increasing soil water absorption and accelerating water movement both on the surface and within the soil matrix. The lack of agricultural utilization of land can lead to the formation of a hard surface crust, which reduces infiltration, saturated hydraulic conductivity, and overall water permeability. Additionally, the formation of a biological soil crust on the surface can further impede infiltration, especially in arid ecosystems where these crusts play a vital role in stabilizing the soil (Al-Naser and Agha, 2024).

Therefore, this study aims to evaluate the effect of adding the mineral amendment (zeolite) on specific water-related properties of gypsiferous soils, such as infiltration and hydraulic conductivity.

Materials and Methods

A laboratory study was conducted in the Soil and Water Resources Laboratory, College of Agriculture, Tikrit University, from October 1, 2022, to October 1, 2023. Three soil samples were selected from different locations with varying gypsum content. These soils were classified as fine, mixed, active, hyperthermic, calcareous, and Typic Torrifluents (Mahmoud and Ismaeal, 2024).

The physical and chemical properties of the studied soils are determined in Table 1. The soil samples were air-dried and sieved through a 2 mm sieve. A total of 1 kg of gypsiferous soil was packed into plastic containers and treated with four levels of zeolite (0%, 1%, 2%, and 3%), with three replications. The treated soils were incubated for 60 days with periodic wetting at field capacity, drying, and mixing. Subsequently, laboratory measurements were conducted, including.

Saturated hydraulic conductivity (Ks)

The soil field was moistened and left for one day. Metal core samplers (5 cm in diameter, 5 cm depth) were inserted to obtain intact soil columns, which were then transferred to the laboratory. The soil columns

Links Researchers

were saturated from the bottom, and a constant water head of 1 cm was applied. The amount of water percolating through the soil over time was measured, and saturated hydraulic conductivity was calculated using Darcy's equation (Hillel, 1982).

$$q = \frac{Q}{A * t} = -Ks\frac{\Delta H}{\Delta L} \quad \dots (1)$$

q = Water flux (LT^{-1}); Q = Discharge (L^3); A = Cross-sectional area of the soil column (L^2); t = Time; Ks= saturated hydraulic conductivity (LT^{-1}); $\Delta H/\Delta L$ = hydraulic gradient; L= length of the soil core (L).

Table 1: *chemical and physical properties of the studied soil.*

S3	S2	S1	Unit	Property
5.39	6.31	6.02	$dS.m^{-1}$	EC
7.19	7.36	7.25	-	pH
22.50	21.87	23.97	$cmol.kg^{-1}$	CEC
1.51	1.50	1.48	$Mg.m^{-3}$	Bulk density (Pb)
2.51	2.48	2.50	$Mg.m^{-3}$	Particle density (Ps)
39.63	39.17	40.60	%	Porosity
25.60	13.29	2.27	%	Gypsum content
0.79	0.93	1.1	%	Organic matter
1.5	1.4	1.2	$mg.kg^{-1}$	Sodium (Na^{++})
18	25	27	$mg.kg^{-1}$	Potassium (K)
187	202	210	$gm.kg^{-1}$	Calcium carbonate ($CaCO_3$)

Field infiltration measurement using the mini disk infiltrometer (MDI)

Infiltration was measured both in the field and in the laboratory using the Mini Disk Infiltrometer (MDI). To properly set up the infiltration measurement device, the following procedures were followed:

- Remove the upper stopper and the suction control tube from the bubble chamber.
- Fill the Marriott chamber (bubble chamber) with distilled water to the appropriate level based on the soil's suction requirement, which should be determined experimentally. It is essential to avoid using water containing salts, as this could clog the porous surface openings.
- Close the upper stopper and suction control tube.
- Push the suction control tube downward until it reaches the Marriott chamber.
- Invert the device.
- Remove the rubber seal surrounding the stainless-steel porous disk.
- Fill the reservoir with water, seal it, and ensure that the porous surface is properly and securely positioned.
- Record the water volume in the reservoir at regular time intervals as it infiltrates the soil. The measurement intervals should be:
- Every 2–5 seconds for sandy soils
- Every 30 seconds for loamy soils
- Every 30–60 minutes for clayey soils

The porous surface must be in proper contact with the soil surface to ensure accurate readings. Data analysis was conducted using specialized computer software, metergroup.com/minidisk-support.

Then use the equation as follows:

$$I = C1T + C2\sqrt{T} \quad \dots (2)$$

Where; I= Cumulative infiltration, C_1= Constant related to the soil hydraulic conductivity, C_2 = soil sorptivity (LT^{-1}).

$$K = \frac{C1}{A} \quad \dots (3)$$

K= soil hydraulic conductivity (LT^{-1}), A= experimental constant without a physical meaning, calculated using the following equations:

$$A = \frac{11.65(n^{0.1} - 1)\exp[2.92(n - 1.9)\alpha h0]}{(\alpha\, r0)^{0.91}} \quad n \geq 1.9 \quad \dots (4)$$

or

$$A = \frac{11.65(n^{0.1} - 1)\exp[7.5(n - 1.9)\alpha h0]}{(\alpha\, r0)^{0.91}} \quad n < 1.9 \quad \dots (5)$$

Where; H= matric potential (L), r_0 = Radius of the mini disk infiltrometer porous (2.25 cm), n and α= parameters from the van Genuchten equation, obtained from soil water retention curve data using the RETC program (Leij *et al*., 1992).

Laboratory soil measurements

After air-drying the soil samples and passing them through a 2 mm sieve, the following physical and chemical soil properties were determined:

Soil texture: Soil texture was determined using the Particle Size Distribution (PSD) method through hydrometer analysis, following the method described by Black *et al.* (1965).

Soil reaction (pH): Soil pH was measured in a 1:1 soil-to-water suspension using a pH meter, following the methodology described by (Page *et al*., 1982).

Electrical conductivity (EC): Electrical conductivity was measured in 1:1 soil: water solution, according to the method (Page *et al*., 1982).

Gypsum content: Gypsum content in the soil was determined through acetone precipitation, according to (Lagerwerff *et al*., 1965).

Calcium carbonate ($CaCO_3$) content: The calcium carbonate content ($CaCO_3$) was determined using the (NaOH) titration method (Richards, 1954).

Organic matter (OM): Organic matter was estimated by organic carbon oxidation using the Walkley and Black method mentioned in (Page *et al*., 1982).

Cation exchange capacity (CEC): It was determined using ammonium acetate according to the method mentioned in (Page *et al*., 1982).

Results and Discussion

Effect of gypsum content of soil and zeolite addition on infiltration rate

Figure 1 shows the effect of gypsum content and zeolite rateon an infiltration rate. Found that a difference in the infiltration rate was observed due to the varying rate of gypsum in the soil. The soil with gypsum content S2 exhibited the highest average infiltration rate of 9.5417 $cm.h^{-1}$, whereas the soil with gypsum content S1 recorded the lowest rate, 6.1583 $cm.h^{-1}$. This is due to the increased dissolution of gypsum. It may increase gypsum deposition due to the increased affinity between water and gypsum in the soil, which enhances the soil's ability to absorb water and increases the movement of water through the soil's surface and structure. This according to found (Abdullah, 2010; Hassan *et al*., 2023).

In addition, the case of the infiltration height and hydraulic conductivity in the soil with higher gypsum content can be attributed to the increased pore size in the soil and increased gypsum content and the enlargement of larger pores due to higher gypsum concentrations boosts water conductivity, particularly under high moisture conditions (Sang *et al*., 2023).

Because addition of zeolite different rates to the soil contributed to increasing the water volume because the zeolite is rich in pores of different sizes and shapes and very small channels that connect the large pores inside the mineral crystals, as zeolite mineral has different secondary building units in the shapes of pore openings and distinctive channel systems. Zeolite mineral is porous and contains voids of different sizes and pores in the form of layers adjacent to the walls of a crystal. Therefore, zeolite has high water and nutrient absorption due to the high porosity of minerals, which is attributed to the three-dimensional structure of a series of interconnected channels improves the physical properties of clay soil, and increases the ventilation and water conductivity of the soil (Mondal *et al*., 2021).

Additionally, a significant interaction between zeolite levels and soil gypsum content was found. The highest infiltration rates were in treatments S2Z4 and S3Z4, both reaching 9.9333 $cm.h^{-1}$ hour, while the lowest infiltration rate was seen in treatment S1Z1, of 5.8333 $cm.h^{-1}$.

Figure 2 also shows effect a significant of the interaction between the soil gypsum content and levels of zeolite addition, as treatments S2Z4 and S3Z4 gave the highest leaching rate 9.9333 $cm.h^{-1}$, while treatment S1Z1 gave the lowest leaching rate values, reaching 5.8333 $cm.h^{-1}$.

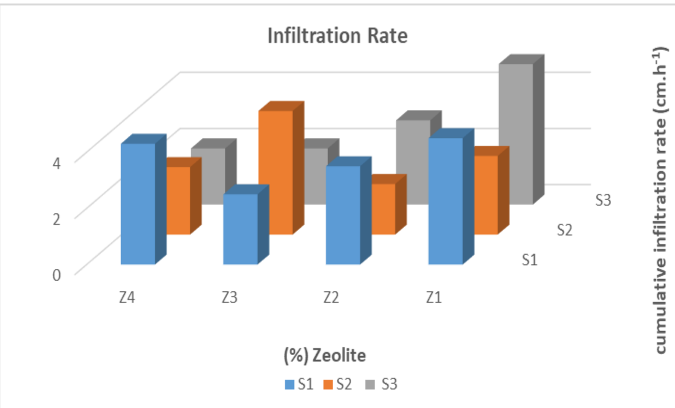

Figure 1: *Effect of gypsum content of soil and zeolite addition on infiltration rate.*

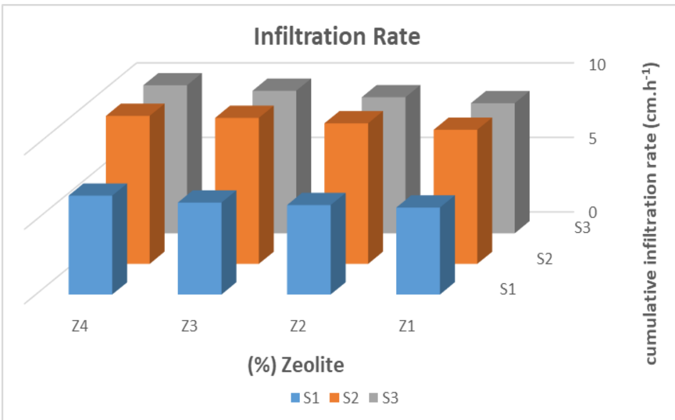

Figure 2: *Effect of the binary interaction of different zeolite levels and soil gypsum content on the infiltration rate.*

Effect of gypsum content of soil and zeolite addition on saturated hydraulic conductivity

Figure 3 presents the influence of soil gypsum content and zeolite addition levels on saturated hydraulic conductivity. A significant variation in the effect of gypsum content on hydraulic conductivity was observed. The soil with gypsum content S2 exhibited the highest average saturated hydraulic conductivity of 6.54 cm per hour, while the soil with gypsum content S1 showed the lowest at 5.51167 cm per hour. This can be attributed to the increased presence of larger pore spaces with higher gypsum content, which improves water conductivity, particularly at higher moisture levels, as indicated by (Mahdi, 2008).

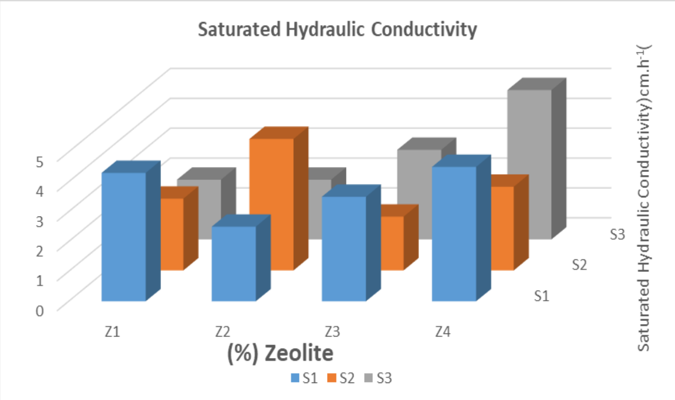

Figure 3: *Effect of soil gypsum content and zeolite addition levels on saturated hydraulic conductivity.*

Zeolite addition to the soil also significantly affected the saturated hydraulic conductivity. Treatment 3% showed the highest average value at 7.03222 $cm.h^{-1}$, while treatment 1% exhibited the lowest at 5.20889 $cm.h^{-1}$. This is because zeolite retains water in the soil due to its distinct pore structure, consisting of different pore sizes and layers that align with crystal walls. The three-dimensional framework of zeolite contributes to improving soil physical properties, especially by increasing aeration and hydraulic conductivity (Hamid, 2025b).

Figure 4 also shows a significant effect of the interaction between the soil's gypsum content and the levels of zeolite addition. treatment showed S2Z4 gave the highest Saturated Hydraulic Conductivity, reaching 7.57333 $cm.h^{-1}$, while treatment S1Z1 gave the lowest values of Saturated Hydraulic Conductivity, reaching 4.80667 $cm.h^{-1}$. Moreover, a significant interaction was found between soil gypsum content and zeolite addition levels. The highest saturated hydraulic conductivity was recorded in treatment S2Z4, with a value of 7.57333 $cm.h^{-1}$, while the lowest was observed in treatment S1Z1 at 4.80667 $cm.h^{-1}$. This means that adding conditioners to the soil improves its physical properties. This is consistent with what was found by (Hamid, 2025a).

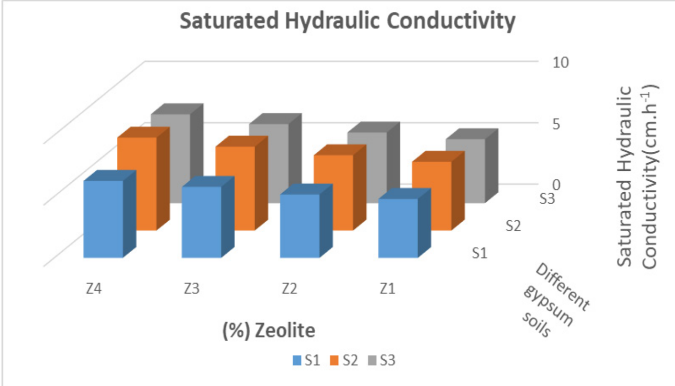

Figure 4: *Effect of the binary interaction of different zeolite levels and soil gypsum content on saturated hydraulic conductivity.*

Conclusions

The inclusion of zeolite had a notable positive impact on improving the water related properties of the gypsiferous soils studied. Increased levels of zeolite addition contributed to the enhancement and elevation of physical water properties, including infiltration rate and hydraulic conductivity.

Acknowledgement

The authors would like to thank the College of Agriculture, Tikrit University, for providing the facilities and support necessary to carry out this research.

Novelty Statement

This study introduces a novel approach to improving water-related properties of gypsiferous soils using natural zeolite in Iraq, specifically targeting variations in gypsum content to enhance infiltration rate and saturated hydraulic conductivity.

Author's Contribution

Roaa Hameed Abed: Investigation, writing, Formal analysis, writing, editing, and resources.
Hiba Abdullah Kareem: supervision, Validation, visualization, review, Conceptualization.

Conflict of interest

The authors have declared no conflict of interest.

References

Abdullah, M.N., 2010. Assessment of water transport functions during horizontal and vertical infiltration for two-water quality of soils with different gypsum content.

Al-Juboori, J.M.Y., A.M. Khairo and W.F. Al-Shamary. 2023. The thermal conductivity and matric potential (Moisture tension) relationships for soils of different gypsum content. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing. 1158(2): 022007. https://doi.org/10.1088/1755-1315/1158/2/022007

Al-Naser, Y.H. and M.D. Agha. 2024. Role of gypsum stone to improve some physical and hydrological properties of heavy soil and yield of sunflower *Helianthus annuus* L. Tikrit J. Agric. Sci., 24(3): 102-109. https://doi.org/10.25130/tjas.24.3.9

Black, C.A., D.D. Evans, L.L. White, L.E. Ensminger and F.E. Clark. 1965. Method of soil analysis. Am. Soc. Agronomy NoR 9 part I and II.

Farhan, M.J., F.A. Alsajri and N.A. Hilai. 2024. Evaluating the efficiency of potassium fertilizer sources and levels on sesame growth and yield in two different gypsum soils. Tikrit J. Agric. Sci., 24(1). https://doi.org/10.25130/tjas.24.1.13

Hamid, M.Q., 2025a. Mycorrhiza and Trichoderma fungi role in improving soil physical properties planted with maize (*Zea mays* L.). SABRAO J. Breed. Genet., 57(1): 260-269. https://doi.org/10.54910/sabrao2025.57.1.25

Hamid, M.Q. 2025b. Response of physical properties of sandy soil treated with different levels of natural soil conditioners zeolite and perlite. Sarhad Journal of Agriculture, 41(2): 591-599. https://dx.doi.org/10.17582/journal.sja/2025/41.2.591.599

Hassan, D., T. Thamer, R. Mohammed, A. Almaeini and N. Nassif. 2023. Calibration and evaluation of aquacrop model under different irrigation methods for maize (*Zea mays* L.) in central region of Iraq. In: (ed. A. Kallel *et al.*) selected studies in environmental geosciences and hydrogeosciences. CAJG 2020. Advances in Science, Technology and Innovation. Springer, Cham. https://doi.org/10.1007/978-3-031-43803-5_10

Hillel, D., 1982. Introduction to soil physics. Academic press. New York. pp. 12. https://doi.org/10.1016/B978-0-08-091869-3.50005-6

Hu, G., J. Yang, X. Duan, R. Farnood, C. Yang, J. Yang and Q. Liu. 2021. Recent developments and challenges in zeolite-based composite photocatalysts for environmental applications. Chem. Eng. J., 417: 129209. https://doi.org/10.1016/j.cej.2021.129209

Jafaar, A.A., R.J. Mohammed, D.F. Hassan and T.Y. Thamer. 2023. Effect of foliar seaweed and different irrigation levels on water consumption, growth and yield of wheat. IOP Conf. Ser. Earth Environ. Sci. IOP Publ., 1252(1): 012057. https://doi.org/10.1088/1755-1315/1252/1/012057

Javaid, A., N. Munir, Z. Abideen, Z.S. Siddiqui and J.W.H. Yong. 2024. The role of natural and synthetic zeolites as soil amendments for mitigating the harmful impacts of abiotic stresses to improve agricultural resilience. Plant Stress, pp. 100627. https://doi.org/10.1016/j.stress.2024.100627

Khaleque, A., M.M. Alam, M. Hoque, S. Mondal, J.B. Haider, B. Xu and M.A. Moni. 2020. Zeolite synthesis from low-cost materials and environmental applications: A review. Environ. Adv., 2: 100019. https://doi.org/10.1016/j.envadv.2020.100019

Lagerwerff, J.V., G.W. Akin and S.W. Moses. 1965. Detection and determination of gypsum in soils. Soil Sci. Soc. Am. J., 29(5): 535-540. https://doi.org/10.2136/sssaj1965.03615995002900050019x

Leij, F.J., M.T. Van Genuchten, S.R. Yates, W.B. Russell and F. Kaveh. 1992. RETC: A computer program for analyzing soil water retention and hydraulic conductivity data. Indirect methods for estimating the hydraulic properties of unsaturated soils. Univ. Calif. Riverside, pp. 263-272.

Mahdi, N.T., 2008. The effect of gypsum content on the moisture characteristic curve and unsaturated hydraulic conductivity of soil. Iraqi J. Agric. Sci., 39(3): 10-23.

Mahmoud, H.I. and A.S. Ismaeal. 2024. Pedogenic and spatial distribution of gypsum content in soil series units in Al-Dur District in Salah Al-Din Governorate. In: IOP Conf. Ser. Earth Environ. Sci. IOP Publ., 1371(8): 082051. https://doi.org/10.1088/1755-1315/1371/8/082051

Mondal, M., B. Biswas, S. Garai, S. Sarkar, H. Banerjee, K. Brahmachari and A. Hossain. 2021. Zeolites enhance soil health, crop productivity and environmental safety. Agronomy, 11(3): 448. https://doi.org/10.3390/agronomy11030448

Nakhli, S.A.A., M. Delkash, B.E. Bakhshayesh and H. Kazemian. 2017. Application of zeolites for sustainable agriculture: a review on water and nutrient retention. Water, Air, Soil Pollut., 228: 1-34. https://doi.org/10.1007/s11270-017-3649-1

Page, A.L., R.H. Miller and D.R. Keeney. 1982. Methods of soil analysis. Part 2. Chemical and microbiological properties. Agronomy, No. 9. Soil Sci. Soc. Am., Madison, WI, 1159. https://www.cabidigitallibrary.org/doi/full/10.5555/19841981415, https://doi.org/10.2134/agronmonogr9.2.2ed

Richards, L.A., 1954. Diagnosis and improvement of saline and alkali soils. USDA Agric. Handbook 60. Washington, D.C. https://doi.org/10.1097/00010694-195408000-00012

Sang, T., A. Kang, Y. Zhang, B. Li, H. Mao and H. Kong. 2023. Effect of different ameliorants on the infiltration and decontamination capacities of soil. Materials, 16(7): 2795. https://doi.org/10.3390/ma16072795

Zhang, R., Z. Sun, G. Li, H. Wang, J. Cheng and M. Hao. 2020. Influences of water chemical property on infiltration into mixed soil consisting of feldspathic sandstone and aeolian sandy soil. Sci. Rep., 10(1): 19497. https://doi.org/10.1038/s41598-020-76548-7