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Effect of zeolite on some physical and water properties of soil cultivated with chickpeas

Esraa Hussein Mohammed[1] **Faris A. Al-wazzon[2]**

Department of Soil and Science and Water Resources, College of Agriculture and Forestry, University of Mosul, Iraq[1,2]

esraa.25agp97@student.uomosul.edu.iq[1]

Dr.farisakram@uomosul.edu.iq[1,2]

I. Abstract

Undisturbed surface soil samples were collected from two sites in Nineveh Governorate, northern Iraq: one with a clayey texture and the other with a silty clayey texture. The soil was transported and placed in 8 kg pots, ready for chickpea planting. Natural soil amendments, specifically zeolite at 1% and 2% levels, were added to the pots to determine their effect on soil water properties during the 2024-2025 growing season. Different percentages of available water were used: 25%, 50%, and 75%, under varying soil separation conditions. The aim of this study was to determine the effect of zeolite on soil physical properties under different levels of water stress, varying percentages, and varying clay separation levels. A randomized complete block design (RCBD) was employed. The results showed that zeolite had a clear effect on increasing the upper and lower limits of plasticity with changing the percentage of zeolite, as a percentage of 2% had higher limits in raising the lower and upper limits of plasticity. The levels of available water contributed to explaining these values. The results showed that using 50% led to an increase in both the lower and upper limits, and at different textures with a high percentage of clay to the first location, in a clear increase in the plasticity index compared to the other location. Therefore, using zeolite at a percentage of (25, 75)% had a lesser effect than 50%, which gave the best results. More than 1% achieved the best results and crop growth as a vegetative and root system was excellent compared to the other treatments.

Key words: Zeolite; hydraulic functions; Liquid limit; plastic limit.

II. Introduction

Zeolite is a highly crystalline aluminosilicate mineral belonging to the silica group. It consists of a three-dimensional network of interconnected silica crystals with water-filled channels. Li et al. (2025) indicated that ion exchange in zeolite is influenced by several factors, including the concentration and nature of anions and cations, pH, and the crystal structure of the zeolite. The cation attraction increases with increasing valence, and in isovalence cases, the attraction is determined by the ion's radius of hydration. Zeolite is inexpensive, widely available, and possesses high cation exchange capacity and good structural stability, even under acidic conditions. This has made it a valuable material for heavy metal adsorption (Wazzan, 2025; Al-Alvarez et al., 2003). Chickpeas (Cicer arietinum L.) are an important legume crop and a winter crop. They are characterized by a moderate growing season and relatively low water consumption. Chickpeas are considered a high-nutritional-value crop compared to other legumes and are the second most economically important legume crop globally. They are also a source of healthy plant protein (Mathew et al., 2022). Chickpea cultivation, like other field crops, is directly affected by the prevailing climate during the growing season and by soil properties (Khajehpour, 2000; Mohammed et al., 2022). Zeolite is characterized

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by a high cation exchange capacity (CEC) of 100–200 centimol kg⁻¹, in addition to several other properties, including high water retention capacity and ion exchange capacity (Stylianou et al., 2025). Bhattacharyya et al. (2015) noted that zeolite possesses distinctive physical properties such as a high percentage of open spaces, low bulk density, and a high cation exchange capacity (150–250 cmol/kg⁻¹). Zabochnicka-Swiatek (2007) explained that the high cation exchange capacity of zeolite is due to its unique silicate structure, which provides it with open cavities in the form of channels occupied by water molecules and cations, making it capable of ion exchange. The use of natural soil amendments and organic fertilizers improves the physical, chemical, and fertility properties of the soil, creating a favorable environment for plant growth by increasing nutrient content and providing essential nutrients. Zeolite is a significant and widely used soil amendment in agriculture, improving soil properties, treating contaminated soils, regulating soil reaction, and enhancing the efficiency of applied fertilizers (Mondal et al., 2021). Noori et al. (2006) demonstrated that the use of natural zeolite in saline soils improves soil properties and increases agricultural productivity. This is achieved by reducing soil electrical conductivity through the trapping of salinizing ions away from the root zone. Additionally, it increases soil nutrient content, particularly ammonium and potassium. This is attributed to the structural composition of zeolite, which traps positive ions and releases them to the plant when needed, thus reducing the amount of fertilizer required by increasing fertilizer efficiency and extending its retention period. Zeolite affects plasticity and fluidity boundaries, as well as soil reclamation, and helps reduce the plasticity coefficient between clay particles (Chenarboni et al., 2022). Zeolite improves plasticity boundaries, preventing soil compaction around germinating seeds and protecting roots from rot caused by excess water accumulation, as the pores of the zeolite distribute moisture evenly (Mondal et al., 2021).

Soil is the essential medium for crop growth, and its physical properties, particularly plasticity, play a crucial role in determining the extent and ease of root penetration and nutrient absorption (Mancinell et al., 2025). Zeolite affects plasticity, which is the soil's ability to change shape under external forces without cracking. It does so by modifying the Atterberg limits. It works by raising the liquid limit and plastic limit in heavy clay soils. This means that the soil remains cohesive and malleable over a wider range of moisture content, thus reducing sudden drying and improving the texture of soils grown for chickpeas, which are often clayey to loamy (Molaabasi et al. 2021). Zeolite offers significant advantages for improving root aeration by reducing excessive plasticity in moist soils. This allows oxygen to reach the root nodules, which are responsible for nitrogen fixation, and facilitates root penetration. Zeolite-enriched soils have lower mechanical resistance, allowing chickpea taproots to penetrate deeper and access moisture (Jabbar et al., 2025). Various studies have indicated that adding zeolite at a rate of 5% to 10% of soil weight leads to a significant decrease in the plasticity index and an increase in the soil's ability to withstand mechanical stress from agricultural machinery. Soil physical properties include bulk density, aeration, porosity, and water retention capacity. Bulk density is the primary soil property, influencing total porosity, surface soil stability (Robinson et al., 2022), soil structure, and its ability to retain maximum moisture, which plants can utilize during periods of drought. Zeolite, a natural soil amendment, possesses several important properties that make it highly desirable for improving soil physical and hydrological properties, including high porosity, which leads to... It increases the soil's storage capacity due to its uniform particle sizes, high moisture-retention exchange capacity, and selectivity in the arrangement and distribution of cations such as potassium. It can also be used as a nutrient storage medium and release them when needed (Jabbar et al., 202).

Zeolite is characterized by its interconnected channel and passage structure, which allows for good water and ionic nutrient retention, giving it a high absorption capacity. Zeolite has a large surface area that facilitates penetration. Therefore, it can be used as a natural agricultural improver in sustainable agricultural production, as it exhibits slow-release properties for essential nutrients and moisture content (Nunez et al.,

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2024). The unique physical and chemical properties of zeolite enable it to regulate water and cation circulation within the soil, making them available when needed. Zeolite is considered an essential mineral for enhancing soil structure and building due to its distinctive physical properties (Kanagalabavi et al., 2024). Gholami et al. (2025) demonstrated that adding zeolite as a soil amendment to sandy soils, either alone or mixed with organic and mineral fertilizers, increased cation exchange capacity and organic matter content, improved the chemical properties of these soils, reduced soil salinity, increased phosphorus and potassium availability, and enhanced plant growth and productivity. Therefore, the mineral plays a vital role in sandy soils where nutrients and water are subject to loss. These results align with those of Modeal et al. (2021), who found that zeolite contributes to sustainable agricultural systems by preventing environmental problems through increased availability of essential elements and improved water use efficiency in the soil. Adding natural zeolite to poor clay soils increases their fertility. It was found that zeolite controls the release of nitrogen from the soil and that it retains micronutrients, especially iron, copper and manganese, and supplies them to the plant when needed (Golami et al., 2024).

III. Materials and Methods

Basic chemical analyses were performed on soil samples from the two study sites, using different ratios and all treatments. Electrical conductivity (EC), soil pH, and soil pH in a 1:1 soil:water extract were determined using a pH meter, as described in Barthakur and Baruah (1999).

The 1:1 soil extract was used to estimate dissolved ions such as calcium and magnesium. A flame photometer was used to measure sodium and potassium in the same extract, as described in Tandon (1999). Carbonates and bicarbonates were estimated by titration in soluble anion equivalents, as described in Page et al. (1982). The cation exchange capacity (CEC) was estimated as described in Arter (1993). Total calcium carbonate was estimated for the two study sites, which are characterized as calcareous soils due to their calcareous origin, as described in Richards (1954). The particle size distribution of soil fractions was estimated to determine soil texture classification using hydrometry for soil samples from the two study sites, as described in Bauder and Gee (1986). Undisturbed soil samples were taken to the laboratory using a metal cylinder with a diameter of 4.6 cm and a height of 5 cm to measure bulk density, an important physical property, as described in Klute (1986).

$\rho b = Ms/Vt$……………………………………………...(1)

pb =Bulk densit Mg m^{-3} ; Ms = The mass of the solid in gm; Vt = total volume cm^3

The total porosity was calculated using the following relationship:

$$\text{Porosity\%} = \frac{Apear\ density - 1}{Real\ density} \times 100 \qquad (2)$$

The value of ks was calculated using the variable water column method on an undisturbed soil sample, as described by Klute (1986), in metal cylinders, according to the equation:

$Ks = aL/At \ Ln \ H_1/H_2$…………………………………………(3)

Ks = Saturated Hydraulic Conductivity cm s; a = Cross-sectional area of the water column cm^2
L =Length of the soil column cm
A = Cross- sectional area of the soil column cm^2
t = Time sec

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H_1 = Height of the water column at the beginning of the experiment from the water flow point cm
H^2 = Height of the water column at the end of the experiment from the water flow point cm.

3**. Estimation of Plasticity Limits**:

The maximum plasticity limit was estimated for all soil samples taken directly from the field using the Atterberg device, as described by Lambe (1951). This represents the maximum plasticity limit before planting. The maximum plasticity limit was also determined for all pots and treatments after planting.

The minimum plasticity limit for soil samples was estimated by creating 3 mm diameter threads from the soil paste and shaping them into rings without cracking or breaking, as described by Lambe (1951). The plasticity index was calculated using the following relationship, as described by Baruah (1999) (Barthakur and

Pl = LL - PL ……………………………………………(4)

PI = Plasticity Index Liquid Limit , = LL

Plastic limit = PL.

4. Clay effectiveness

Clay effectiveness was determined by the ratio between the plasticity index and the percentage of clay, as stated in (Lambe, 1951).

Clay effectiveness = plasticity index / clay % ………… (5)

These characteristics allow for the study of the clay behavior of different samples and its correlation with soil moisture content, as well as the effect of soil amendments on clay properties and its moisture retention capacity.

To observe the proportion and quantity of essential elements in the soil before and after the addition of soil amendments, and to estimate available nitrogen and phosphorus, available nitrogen was extracted from the soil using a potassium chloride solution (2M KCl). The nitrogen in the extract was then determined using the Kejldhal method, as described in Tandon (1999). Meanwhile, available phosphorus was extracted from the soil using a sodium bicarbonate extraction solution (0.5 M) at a reaction temperature of 8.5. The extracted phosphorus was then determined calorimetrically using a spectrophotometer at a wavelength of 882 nm, according to the method described in Tandon (1999). The organic matter was estimated by the wet oxidation method using potassium dichromate $K_2Cr_2O_7$ (1 M) and concentrated sulfuric acid for the purpose of oxidizing the organic matter, then titration with ammonium sulfate (Rowell, 1996).

IV. Results and Discussion

5.1. Chemical Analysis of the Study Soils

The results, shown in Table (1), indicate that the pH values for both study sites and all treatments ranged between (7.1 and 7.9), thus being neutral for both sites and all treatments. The study results also revealed a significant and clear difference in the electrical conductivity (EC) value. For the first soil site, the EC values ranged between (1.55, 1.27, and 1.73) when irrigated with a ready water percentage of (25, 50, and 75)%, respectively, for the treatment without additives. These values increased to (1.59, 2.07, and 1.75) dS/m for the treatment with a 1% zeolite addition. This increase is attributed to the fact that zeolite is an aluminosilicate mineral containing a good percentage of cations, which led to a slight increase in the electrical conductivity values, reflected in the percentage And an increase in cations. The results showed that

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increasing the percentage of zeolite added by 2% to the same site led to an increase in the value of (EC) compared to the treatment with zero addition, 1% addition, as the results were (1.99, 2.24 and 2.29) deciSiemens m1- when irrigating with (25, 50 and 75)% of the available water. This proves that increasing the percentage of zeolite leads to an increase in the values of electrical conductivity in a manner directly proportional to the percentage of zeolite added. This is consistent with the results of Chourasia et al. (2024). The results also showed that adding zeolite to the soil at the second site, which has a clayey-silty texture, led to a significant increase in EC values compared to the first site. The electrical conductivity of the soil samples without zeolite addition was 2.39, 2.25, and 2.42 dS/m for irrigation treatments of 25%, 50%, and 75% of available water, respectively. These values increased when zeolite was added, reaching 3.68, 3.52, and 3.16 dS/m for irrigation treatments of 25%, 50%, and 74% of available water. The highest values were observed when the soil was treated with 2% zeolite, reaching 3.72, 3.8, and 3.91 dS/m, respectively. This clearly indicates the direct effect of zeolite soil improvers in bringing about chemical changes, most importantly (EC), in soils with a medium clayey silt texture compared to the slight change in clay soils at the first site. This was reflected in the rest of the soil properties, such as the ratio of cations and anions, as noted in Table (1).

Table1. some of chemical properties of sand under study

Treatments	PH	EC dSm^{-1}	^{+}K	^{+}Na	^{+}Ca	^{+}Mg	^{-}Cl	CO_3^{-1}	HCO_3	So_4	TOTAL CARBONATES g gk^{-1}	CEC Cmolc Kg^{-1}
	mmol$_c$ l^{-1}											
$T_1Z_0I_{25}$	7.6	1.55	0.171	0.204	9.4	4.5	1.2	0	4	9.02	301	19.21
$T_1Z_0I_{50}$	7.7	1.27	0.171	0.204	7.2	4.5	1	0	5.5	0.47	295	21.13
$T_1Z_0I_{75}$	7.8	1.73	0.245	0.449	10.4	6	1.4	0	5.5	10.5	290	22.47
$T_1Z_1I_{25}$	7.5	1.59	0.294	0.204	9	5	1.6	0	8	4.79	305	23.78
$T_1Z_1I_{50}$	7.6	2.07	0.270	0.245	11	8	1.4	0	5.5	12.51	285	24.82
$T_1Z_1I_{75}$	7.7	1.75	0.270	0.286	11	6	2.4	0	4.5	10.55	280	25.11
$T_1Z_2I_{25}$	7.1	1.99	0.147	0.449	10.4	8	1	0	5.5	12.40	300	27.52
$T_1Z_2I_{50}$	7.4	2.24	0.196	0.245	12.2	9.7	1.2	0	5.5	15.54	288	30.50
$T_1Z_2I_{75}$	7.2	2.29	0.196	0.245	13.4	7.6	1.4	0	5.0	15.01	280	31.65
$T_2Z_0I_{25}$	7.9	2.39	0.245	0.572	11.5	10.5	1.6	0	11.5	9.61	275	12.30
$T_2Z_0I_{50}$	7.9	2.25	0.245	0.531	10.8	10	1.8	0	10.4	9.17	250	14.19
$T_2Z_0I_{75}$	7.9	2.42	0.245	0.449	12.2	11	2.2	0	14	7.59	230	14.96

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$T_2Z_1I_{25}$	7.9	3.68	0.220	1.103	17.4	16	2	0	11.5	21.10	275	18.15
$T_2Z_1I_{50}$	7.9	3.52	0.245	1.144	18.8	15	3.6	0	10.5	21.02	250	19.86
$T_2Z_1I_{75}$	7.8	3.16	0.220	0.572	14.5	16	2	0	10.5	18.69	243	20.65
$T_2Z_2I_{25}$	7.9	3.72	0.220	1.226	19.1	15.7	3.2	0	10.5	22.44	275	26.52
$T_2Z_2I_{50}$	7.8	3.8	0.147	0.531	2.06	16	3.4	0	5.5	28.27	275	31.00
$T_2Z_2I_{75}$	7.8	3.91	0.220	1.307	21	17	3.2	0	11	25.22	275	32.26
Clay soil before planting	7.6	0.27	0.098	0.122	1.2	1.28	0.4	0	6.5	4.2	305	20.45
Clay silt mixture before planting	7.9	1.27	0.171	0.408	6.2	5.3	1.2	0	12.5	1.60	277	15.62

As we can see from the table, the total carbonate content of the two study sites ranged from 277 to 305 g/kg¹ before planting for the second and first sites, respectively. After planting, and as a result of adding soil amendments at different levels of available water (25%, 50%, and 75%), clear changes occurred in the total carbonate content of the soils placed in the pots. This content decreased with increasing levels of available water. This is due to the washing and displacement of some of these carbonates from the surface layer of the pots to the bottom. There was a slight decrease in total calcium carbonate with increasing watering of the pots with available water. It is noted that the direct effect of zeolite on changing the total carbonate content was not apparent, but rather the change was influenced by the amount of water used to irrigate the pots, depending on the available water content, as shown in the table. The results in the table showed that the highest values of cations and anions were in the clay-silty loam soil texture for the zeolite addition treatments of 1% and 2%. This indicates the effect of zeolite in supplying the soil with a good percentage. The cations and anions in this soil were clearly visible, with the highest values observed in treatment T2Z2I75. This was due to raising the EC value to 3.91, which significantly increased the percentage of cations and anions, particularly sodium, which reached 1.307 milliequivalents per liter.

Zeolite is considered one of the most effective soil amendments for increasing cation capacity (CEC) because of its high surface area and negative charge in its crystal structure. This type of soil amendment contributes to raising CEC, especially in poor soils with low clay and organic matter content. Zeolites also help the soil retain cations, particularly calcium, magnesium, and potassium, and reduce their leaching loss in the irrigation system.

This leads to better soil retention – a clear effect of zeolites has been observed in light-textured soils, and the effect is more pronounced but to a lesser extent than in clay soils. The higher the percentage of zeolite added to the soil, the greater the improvement.

The results showed that adding zeolite improved the cation exchange capacity (CEC) values of the soils at both study sites and for all treatments. The improvement and increase in CEC values was greater in

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the soil site with a clay-silty loam texture because this texture had a clay content of 52.5%, which is lower than the clay content at the other site (40%). Therefore, the effect of zeolite was more pronounced in the intermediate texture than in the clay texture. CEC values ranged from 12.30 to 14.19 to 14.96 in the treatments that did not add zeolite. It was observed that the values increased with increasing irrigation percentages (25%, 50%, and 75%). This may be because the moisture content contributed to a slight increase in CEC values. However, it should be noted that adding high quantities of water (over 75%) leads to cation leaching without utilization, which did not occur in our study due to controlling the moisture content values based on the available water content did not exceed 75% of the total available water (Xu et al., 2021). The results for this site showed a clear improvement in the cation exchange capacity (CEC) values after the first application, with values increasing to (18.15, 19.86, and 20.65) cnm·kg⁻¹ soil. This clearly demonstrates the effect of the amendments in raising the CEC values. These values increased further with increasing zeolite addition, reaching (26.52, 31.00, and 32.26) cnm·kg⁻¹ soil, representing the highest increase due to the higher quantity of zeolite added.

In the first site, with its clayey texture, an increase in CEC values was also observed with the addition of zeolite and an increase in moisture content, depending on the available water (as shown in the table). The results showed that the cation exchange capacity (CEC) values of this soil were higher than those of the second site, which had treatments without zeolite addition. This is due to the high clay content. The limiting factor in increasing the CEC is the high clay content. An increase in CEC values was observed with the zeolite addition treatment and at different irrigation levels of available water, reaching (23.78, 24.82, and 25.11) cmol·charge·kg. In the second soil treatment, the results showed an increase in CEC values with the addition of zeolite at 25%, 50%, and 75% of available water.

CEC values reached (27.52, 30.50, and 31.65) cmol·charge. 1 kg - soil. This is directly evident in the effect of soil improvers in raising CEC values with increased available water. However, the percentage of improvement in cation exchange capacity values for clay soils was relatively less than the second texture. Adding zeolite as a soil improver gave a clear direct effect in soils with low clay content. This is consistent with what was indicated by (Satriani et al., 2025), who stated that the use of zeolite as a soil improver is more effective in poor and sandy soils compared to clay soils.

5.2. Physical Analysis of the Study Soils

The results in the table show a difference in the physical properties of the study soils. This can be interpreted as a difference in the proportions of soil separators at the two study sites.

Table (2) Physical Properties of the Study Soils

Location	Soil separates g kg $^{-1}$			Pb Mg m^{-3}	Total % porosity	Initial volumetric water content Cm^3 Cm^{-3}	Soil Texture
	طين	غرين	رمل				
Firet	525	375	100	1.37	48.30	0.200	طينية
Second	400	425	175	1.11	58.11	0.175	مزيجيه طينية غرينية

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The results showed that the soil at the first site was characterized by a high clay content, reaching 525 g/kg$^{1-1}$. Therefore, the soil is classified as clay soil with an initial bulk moisture content of 0.200. In contrast, the soil at the second study site, located in the area of the second site, had a clay content of 400 g/kg$^{1-1}$ and a high silt content of 425 g/kg$^{1-1}$, placing it within the clay-silty loam soil structure, characterized by an initial bulk moisture content of 0.175. This difference in soil composition and silt content between the two study sites allows for the investigation of the impact of adding different levels of zeolite at varying levels of available water. This provides a scientific explanation for the use of soil amendments at different ratios and with varying physical and hydraulic properties.

5.3. Saturated Water Conductivity

Table (3) shows the saturated water conductivity (ks) values for the two study sites and all treatments. The results showed a clear effect of zeolite on the saturated water conductivity values. It was observed that the first site, with its clayey texture and high clay content of 525 kg, had values of (1.08, 1.25, 1.36) cm/h for treatments where no soil amendments were added, and (25, 50, 75)% respectively of available water.

Table (3) Saturated Water Conductivity Values for All Treatments

first location (parameters)	Saturation water conductivity Cm. Hr^{-1}	Clay content in grams per kilogram	Second location (parameters)	Saturation 1water conductivity Cm. Hr^{-1}	Clay content in grams per kilogram
$T_1Z_0I_{25}$	1.08	525	$T_2Z_0I_{25}$	2.09	400
$T_1Z_0I_{50}$	1.25		$T_2Z_0I_{50}$	2.132	
$T_1Z_0I_{75}$	1.36		$T_2Z_0I_{75}$	2.201	
$T_1Z_1I_{25}$	1.129		$T_2Z_1I_{25}$	1.88	
$T_1Z_1I_{50}$	1.338		$T_2Z_1I_{50}$	1.91	
$T_1Z_1I_{75}$	1.55		$T_2Z_1I_{75}$	1.96	
$T_1Z_2I_{25}$	1.370		$T_2Z_2I_{25}$	1.68	
$T_1Z_2I_{50}$	1.624		$T_2Z_2I_{50}$	1.72	
$T_1Z_2I_{75}$	1.962		$T_2Z_2I_{75}$	1.80	
Before planting	1.091		Before planting	2.05	

It was observed that the amount of irrigation water relative to the available water affected the increase in KS values. This may be due to the fact that as the amount of water increased in the experimental

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treatments, it led to the dissolution and downward movement of salts under the influence of the irrigation water, thus increasing water movement. The results also showed that the use of soil amendments (zeolite) at a level of (1)% led to an increase in the water conductivity in clay soils. This led to an increase in the percentage of effective (small) pores and large pores, which in turn was reflected in an increase in the speed and movement of water. This effect was more pronounced with the use of a zeolite percentage of (2)%, where the values of saturated water conductivity increased to (1.370, 1.624, 1962) hours. This indicates that the use of zeolite in clay soils led to a faster movement of water within the porous medium, and this speed increases with an increase in the percentage of addition and an increase in the amount of irrigation water used. This is consistent with what was indicated by (Liliya et al., 2020), who stated that the use of different soil amendments, whether Whether organic or synthetic, it often leads to an increase in the saturated water conductivity values of clay soils.

While the results for the second site, with its clayey-silty soil texture and clay content of 400 g/kg, showed that adding zeolite had a different effect than in the first site, the values for the treatments without zeolite addition were 2.09, 12.132, and 2.201, compared to the irrigated treatments of 25%, 50%, and 75% of available water. The high values in these sites are attributed to the large pore size and the formation of wide pathways due to the fine texture of the separated silt and sand particles, which affected the saturated water conductivity values and increased their percentages. The results also showed that adding 1% zeolite to the soil led to a decrease in the saturated water conductivity values, reaching 1.88, 1.91, and 1.96 for the irrigated treatments of 25%, 50%, and 75% of available water, respectively. This decrease in saturated water conductivity values reflects an improvement in moisture retention and overall soil health. In terms of water balance, when soil amendments are added, zeolite reduces the percentage of water channels within the soil, thus increasing its moisture retention capacity. Therefore, zeolite is considered an effective material for improving the moisture content of light and medium soils. This effect was more pronounced when treating with 2% zeolite, where the saturated water conductivity values reached (1.68, 1.72, 1.80) at (25, 50, 75)% of available water. This clear decrease in the saturated water conductivity values of silty clay loam soils reflects the significant improvement in moisture retention with increasing zeolite content. This aligns with the findings of Hesham et al. (2021), who indicated that zeolite has a greater impact on the water properties of light soil textures compared to clay soil textures. Table (4) shows the minimum and maximum values for plasticity, plasticity index, and clay activity, which are important physical properties for soil conformability and provide a picture of its suitability. Regarding water retention, the results showed a clear difference in the liquidity and plasticity limits of the two study sites. The determining factor for increasing the soil's ability to retain moisture is the percentage of clay, due to its large specific surface area and consequently its higher ability to retain moisture. It was observed that the soil at the first site, with a high clay texture (52.5%), had lower values of (24, 25.3, and 23) and higher values of (35.5, 34.6, and 33.2) under irrigation treatments of (25, 50, and 75)% of available water. These values indicate good ability to retain a high level of moisture. A decrease in the liquidity and plasticity limits was observed under the 75% available water treatment. This may be due to the use of high quantities of irrigation water, which leads to the downward movement of fine soil particles due to the increased moisture content. This movement of clay particles affects the soil and reduces its ability to retain moisture. This is consistent with what was indicated by (Al-Wazzan (2025) indicated the downward movement of fine clay particles and a change in the finer soil texture in the subsurface layers due to irrigation.

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Table (4) Plasticity, Fluidity, and Clay Activity of the Study Soils

Parameter	% clay	Minimum plasticity limit	Maximum plasticity limit	Plasticity guide	Clay activity
الموقع الاول قبل الزراعة		17.6	25.2	7.6	0.144
$T_1Z_0I_{25}$	52.5	24	32.5	11.5	0.219
$T_1Z_0I_{50}$		25.3	34.6	9.3	0.177
$T_1Z_0I_{75}$		23	33.2	10.2	0.94
$T_1Z_1I_{25}$		25	36.8	11.8	0.224
$T_1Z_1I_{50}$		26.5	37.2	10.7	0.203
$T_1Z_1I_{75}$		23.4	33.7	10.3	0.196
$T_1Z_2I_{25}$		27.6	39.8	12.2	0.232
$T_1Z_2I_{50}$		27.8	40.5	12.7	0.238
$T_1Z_2I_{75}$		26.5	40	13.5	0.257
الموقع الثاني قبل الزراعة		20.8	30.8	10	0.250
$T_2Z_0I_{25}$	40	21	30.1	9.1	0.227.
$T_2Z_0I_{50}$		22.1	31	8.9	0.222
$T_2Z_0I_{75}$		20.3	29.8	8.5	0.237
$T_2Z_1I_{25}$		21.9	31.3	9.4	.0.235
$T_2Z_1I_{50}$		23	33	10	0.250
$T_2Z_1I_{75}$		22.8	36.7	13.9	0.347
$T_2Z_2I_{25}$		24.3	36	11.7	0.292
$T_2Z_2I_{50}$		25	36	12	0.300
$T_2Z_2I_{75}$		23.4	37.5	14.1	0.352

The results also showed a slight change in the values of the plasticity and liquidity limits when using zeolite by 1%. These values increased to reach (25, 26.5 and 23.4) and (36.8, 37.2 and 33.7) for the plasticity and liquidity limits respectively at irrigation treatments of (25, 50 and 75)% of available water. This slight increase is due to the effect of zeolite in increasing the ability of clay soil to retain moisture. These values improved even more when using 2% zeolite, reaching (27.6, 27.8 and 26.5) and (39.8, 40.5 and 40) for plasticity and fluidity respectively when treated with irrigation at (25, 50 and 75)% of available water. This

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may be due to the fact that zeolite led to a change in the soil's ability to retain moisture with an increase in the amount added to the ability to bind between particles and form agglomerates at a small percentage, in addition to the ability to retain moisture, as zeolite is considered one of the soil improvers that has the ability to retain moisture. The results showed that the plasticity and liquidity limits of the soil at the second site, which has a clay-silty loam texture and a clay content of 40%, were lower than those at the Al-Shaykhan site. This was due to the lower clay content and the higher sand and silt content, which have a lower moisture retention capacity because of their larger particle size and smaller surface area compared to clay particles. The results showed that the plasticity and liquidity limits were (21, 22.1, and 20.3) and (30.1, 31, and 29.8) respectively for irrigation treatments of (25, 50, and 75)% of available water. The same effect was observed when using (75)% available water, reducing the plasticity and liquidity limits due to the downward movement of fine particles. This downward movement is a result of using sufficient quantities of water, which dissolves the cementing agents between soil particles, releasing the fine particles and causing their movement.

Clearly downwards. The results indicate that the use of zeolite at a rate of 1% for the treatment of clayey silty soils gave a more clear effect than for clay soils, as zeolite worked to produce two effects in this texture. The first is its ability to retain moisture, as it is one of the natural soil improvers that has a high ability to retain moisture. The second effect is reducing the voids and some of the porous space between soil particles and making them more close together, which gives a greater opportunity for moisture retention. This indicates that zeolite is more effective in improving the water properties of medium-textured soils compared to fine-textured soils. The results showed a clear and significant change in the plasticity and liquidity limits when using 2% zeolite. The plasticity and liquidity limits reached (24.3, 25, and 23.4) and (36, 36, and 37.5) respectively for irrigation treatments of (25, 50, and 75)% of available water. This percentage of zeolite increased the soil's moisture retention capacity more than a 1% zeolite application, which was clearly reflected in the plasticity index values, reaching (11.7, 12, and 14.1) for the irrigation treatments of (25, 50, and 75)% of available water, respectively. Adding zeolite at this percentage to soils with a clay-silty loam texture altered their moisture retention capacity, resulting in better moisture content for the chickpea plants compared to treatments without zeolite. Therefore, zeolite is considered a soil amendment with a beneficial effect on plants. Various soil types, especially those sensitive to drought, benefit from zeolite's ability to provide moisture during periods of scarcity. This aligns with the findings of Ferretti (2024), who stated that zeolite is a natural soil conditioner that provides a good amount of moisture content during droughts. The table illustrates the effect of zeolite on the available nitrogen and phosphorus content in the soil. The results showed a clear effect of adding soil amendments (zeolite) on nitrogen and phosphorus levels. Zeolite acts as a nitrogen reservoir in the ammonium form (NH4) because it absorbs ammonium ions within its structure. This reduces leaching and volatilization, thus improving fertilizer efficiency by slowing nitrification. This, in turn, reduces nitrogen loss as nitrates through leaching, especially when the amount of water applied to the plant is high. The table shows that treatments without zeolite addition resulted in low available nitrogen values, ranging from 0.415% to 0.465% for the original clay soil. However, adding zeolite at a rate of 1% significantly increased the available nitrogen, ranging from 0.825% to 1.125% for the same location. The lowest value was observed when irrigating with 75% ready-mixed water. This may be because the high percentage of ready-mixed water resulted in slow downward leaching of nitrogen, and the leaching rate was low. This is attributed to the zeolite's effect of reducing nitrogen leaching by trapping nitrogen within its structure. This aligns with the findings of Ayaz et al. (2021).

Table (5): Effect of Zeolite on Ready-Mixed Nitrogen and Phosphorus Levels

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Parameter's المعاملات	% N Ready	%P Ready	Organic Matter O.M. g/kg1
$T_1Z_0I_{25}$	0.465	5.1	11.33
$T_1Z_0I_{50}$	0.425	3.3	9.54
$T_1Z_0I_{75}$	0.415	2.8	9.12
$T_1Z_1I_{25}$	1.125	6.6	11.92
$T_1Z_1I_{50}$	1.075	4.3	10.31
$T_1Z_1I_{75}$	0.825	3.2	12.88
$T_1Z_2I_{25}$	1.45	6.8	15.47
$T_1Z_2I_{50}$	1.125	5.4	15.72
$T_1Z_2I_{75}$	1.08	4.8	12.11
$T_2Z_0I_{25}$	0.545	7.8	18.55
$T_2Z_0I_{50}$	0.502	6.7	11.07
$T_2Z_0I_{75}$	0.475	6.2	16.88
$T_2Z_1I_{25}$	0.775	8.2	17.11
$T_2Z_1I_{50}$	0.650	7.3	11.25
$T_2Z_1I_{75}$	0.672	7.1	16.90
$T_2Z_2I_{25}$	1.975	8.7	19.93
$T_2Z_2I_{50}$	1.6	7.5	11.37
$T_2Z_2I_{75}$	1.25	7.8	16.96
Clay soil before planting	0.965	3.7	11.36
Clay silt mixture before planting	1.025	7.2	19.23

It was observed that a 2% zeolite content significantly increased the nitrogen content, as the percentage of soil amendments added led to an increase in available nitrogen. This is clearly evident in the treatment using irrigation at 25% available water, where the amount of nitrogen reached 1.45, and decreased to 1.12 at 50% available water and 1.08 at 75% available water. This clearly demonstrates the movement and transfer of nitrogen with irrigation water due to leaching. However, the effect of zeolite significantly reduced the leaching effect. The results showed an effect of soil amendments on changing soil texture and the percentage of its components. It was observed that the percentage of available nitrogen ranged between

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(0.775, 0.650, 0.672) for the irrigation treatments (25, 50, and 75) of available water, respectively. This was an increase in the percentage of available nitrogen compared to the treatments that did not contain soil amendments, i.e., it reached (0.545). (0.502 and 0.475) for irrigation treatments (25, 50 and 75)% of available water. Although the addition of zeolite resulted in a clear increase in the percentage of available nitrogen, its effect on soil texture was less compared to the first site with the clay texture. Here, the effect of soil texture appears, which played a role in bringing about the increase over the comparison treatments (without addition), as we note in the table. In contrast, the use of 2% zeolite for the clay-silty slurry texture led to a clear increase and rise in the percentage of available nitrogen, reaching (1.975, 1.6 and 1.25) for treatments (25, 50 and 75)% of available water, respectively. The zeolite in this texture worked to improve the soil's ability to retain elements, including nitrogen, clearly, especially at the level of 25% of available water, as we note in the previous table.

The table above illustrates the effect of soil amendments on available phosphorus in the soil. Our results show that zeolite significantly increased phosphorus availability, as it maintains phosphorus availability for plants and reduces phosphorus fixation through its effective role in improving soil pH. The percentage of available phosphorus ranged between 5.1%, 3.3%, and 2.8% for the first site (clay-textured soil) under irrigation treatments of 25%, 50%, and 75% of available water, respectively. These values increased to 6.6%, 4.3%, and 3.2% at the same levels of available water with a 1% application. A 2% application resulted in a significant increase in available phosphorus, reaching 6.8%, 5.4%, and 4.6%, respectively. This indicates that zeolite acts as a reservoir for essential nutrients. Furthermore, it indirectly improves soil aeration and moisture levels in the root zone and enhances plant activity. Microorganisms that contribute to the solubility of phosphorus, and this is clearly reflected in the growth of plant roots and in the clear improvement of vegetative growth. The results also showed that adding zeolite to the second site, which has a clayey-silty soil texture, increased the phosphorus content from (7.8, 6.7, and 6.2)% for treatments without zeolite addition to (8.2, 7.3, and 7.4)% for treatments with 1% zeolite, and then to (8.7, 7.5, and 7.8)% for treatments with 2% zeolite addition, with irrigation using 25%, 50%, and 75% of the prepared water. This clearly indicates the ability of these natural amendments to supply essential soil nutrients in their stored quantities and their ability to provide them gradually and slowly, resulting in a clear improvement in plant growth throughout the growing season. Furthermore, it minimizes the leaching or fixation of these nutrients, although a slight decrease occurred when using 25% of the prepared water, which led to a slight movement of these nutrients through the porous medium of the soil to deeper layers. The table clearly shows the difference in the organic matter content of the two study sites, as the results indicate that the addition of zeolite to the prepared water increased the phosphorus content from (7.8, 6.7, and 6.2)% for treatments with no zeolite addition, to treatments with 1% zeolite addition, and then to treatments with 25% zeolite addition. Zeolite was used in the first site, which has a clay texture and had an organic matter content of 11.36 grams per kilogram before planting. After the growing season, these percentages ranged from 11.33, 9.54, and 9.12 grams per kilogram for treatments without zeolite addition, and from 25%, 50%, and 75% irrigation with available water to irrigated soils. A significant increase in the organic matter content was observed at the same site, reaching 11.92, 10.31, and 12.88 grams per kilogram for the 1% zeolite treatment, and reaching its highest point at 15.47, 15.72, and 12.11 grams per kilogram for the 2% zeolite addition and the 25%, 50%, and 75% irrigation with available water. This clearly demonstrates that the zeolite addition significantly improved the availability of nutrients and increased the organic matter content. These results are consistent with the findings of Hoseini et al. (2023). A significant increase in... These values for the second site, which has a clayey silty texture, were (19.23) grams per kilogram[1] before planting and ranged for treatments after planting (18.55, 10.07 and 16.88) for treatments without addition and became (19.11, 11.25 and 16.90) when using 1% zeolite to reach the maximum amount at 2% of the addition, as it reached (19.93, 11.37 and 16.96)

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grams per kilogram¹ at 2% (25, 50 and 75)% of the available water. This indicates the clear effect of soil amendments in supplying the soil with nutrients and raising the percentage of organic matter and the clear effect of the soil texture within it with the added percentage of zeolite in increasing its ability to retain the maximum amount of organic matter depending on the proportions of soil separators.

6. Conclusion:

This study aimed to determine the importance of using natural soil amendments, including zeolite, in their effect on the soil's water and physical properties, including its plasticity and the extent of its direct impact on the soil's moisture retention capacity under varying levels of available water. This impact is analogous to the arid and semi-arid conditions experienced by important agricultural crops, such as chickpeas. The results showed a direct effect of natural soil amendments in increasing the soil's ability to retain moisture under water stress, represented by different levels of available water. Furthermore, the addition of 2% zeolite significantly improved the soil's ability to withstand longer periods of drought. The study results also showed a clear effect on the properties of soil plasticity at the lower and upper limits of plasticity. The study showed an improvement and increase in the limits of plasticity for the treatments with the addition of 2% compared to the addition of 1% zeolite. The percentage of clay within the soil fractions is a determining factor in all soil improvers and their ability to retain the maximum amount of moisture, while the decrease in the percentage of clay led to good effectiveness of zeolite in binding soil particles and closing large voids, which contributed to a clear improvement in the lower and upper limits of plasticity.

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