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Article

The Effect Of Zeolite And Vertisol Soil Conditioners On The Growth, Yield, And Water Use Efficiency Of Barley (Hordeum Vulgare L.) In Sandy Soils

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Abstract: This study examines the effects of zeolite and vertisol soil conditioners on the growth, yield, and water use efficiency of barley in sandy soils. While significant research has explored the use of soil conditioners to improve physical properties and water retention, a gap remains in understanding their comparative effectiveness under different irrigation levels. A field experiment was conducted using a randomized complete block design with three factors: conditioner type (zeolite and vertisol), conditioner level (0%, 1%, 2%, and 3%), and irrigation levels (60%, 80%, and 100% of EP). The findings revealed that vertisol significantly outperformed zeolite in enhancing spike length, grain yield, and water use efficiency, particularly at higher conditioner levels. The results suggest that vertisol could be a more effective soil conditioner in sandy soils, providing practical implications for improving agricultural productivity in arid regions.

Keywords: Zeolite Conditioner, Vertisol Soil Conditioner, Water Use Efficiency, Sandy Loam Soil, Barley Plant.

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1. Introduction

One of the most serious problems around many countries in arid and semi-arid, such as Iraq is degradation of soil properties. They have high carbonates content, low organic matter and natural vegetation. Its ability to storage water and neutron is low due to low cation capacity Around the world sandy soils have a wide distribution of > 900 million hectare (Driessen et al., 2001), be disturbed in western and southern Iraq, especially Basrah Governorate. They have a porous and weak structure since they lack of cementing agents like clay content, organic matter, understanding their behavior and limitations are also important for sustainable agriculture management practices. In addition, the lands could host a potentially rich groundwater resource that may have important implications for food security in Iraq.

Many studies have been introduced regarding the improvement of physical, chemical and hydraulic properties to be combined with natural conditioners such as lowcost materials that are derived from recourses other than industrial minerals (Saleh et al.,2011; Ismail and Ozawa, 2007). The suitable properties and high water storage capability make the conditioners used to improve soils capable of maintaining a certain nutrient content in soil, such as expansive clay (Pisarovic et al., 2003; Xiubin and Zhanbin, 2001). Bentonite clays application in sandy soil, as described by Eldardiry and El-Hady (2015), is a recommended technology to elevate crop yield and rehabilitation of cation exchange capacity degraded soils through the improvement physical properties which made it capable to hold more water due to reduce the infiltration value. so clay particles have been important to fill and will reduce voids between soil grains.

Zeolite as a conditioner has received significant attention for improving the physical and chemical properties of soil (Yamada et al., 2002). It is a volcanic sedimentary mineral primarily composed of aluminosilicates (AlO4; SiO4) with natural crystalline structures. Zeolites are among the most common minerals in sedimentary rocks (Ramesh and Reddy, 2011). They feature a three-dimensional structure containing weakly bound cations and can undergo hydration and dehydration without altering the mineral's structural composition (Holmes, 1994). The zeolite's crystalline structure allows for reversible exchange of cations with the external environment (Rehakova et al., 2004).

The presence of significant quantities of expansive clays, such as Vertisols, in Iraqi soils found in northern Iraq in the Erbil Plain and southern Iraq in the inland river deltas emptying into the marshes (Dheyab and Al-Alwan, 2004) these clays can be utilized to improve the physical and water retention properties of sandy and gypsiferous soils, which subjected to erosion, or to fixed sand dunes.

2. Materials and Methods

A field experiment was conducted at the tomato crop development project research station affiliated to the Basrah Agriculture Directorate, located to the south-east of Al-Zubair District, at latitude 30° 21' 27.2592" and longtude 47° 44' 14.6142" at the winter season 2016-2017, soil texture is loamy sand, classified Typic Torripsamments (Al-Atab, 2008). Soil samples were collected from the field at three depths (0-15), (15-30), and (30-45) cm, they were dried and then passed through a 2 mm sieve to chemical analyses, while some samples were passed through an 8 mm sieve and received on a 4 mm sieve to determine the physical properties of the study soil, as shown in table1. The methods presented by Black et al. (1965); Van Bavel, (1949); Youker and McGuinness. (1956); Jackson (1958); Page et al (1982), and (Richards (1954) to determine physical and chemical properties. The experiment included three main factors: -The first factor is the type of conditioner, represented by the Vertisol soil conditioner and the zeolite conditioner. The second factor is the conditioner level factor, which was added to both conditioners at three levels of 1, 2, and 3% in addition to the 0% control treatment. The third factor is the irrigation level factor, with three irrigation levels of 60, 80, and 100% Ep calculated from US Pan class E. US Pan class -A-. Vertisol soil was brought from the river delta district in Maysan Governorate (Dheyab and Al-Alwan, 2004), while the zeolite conditioner was obtained from the agricultural departments / Basrah Governorate. Table 2 shows some characteristics of the conditioners before applying the experimental parameters. Then, the experimental plot was plowed in two perpendicular plows using a rotary plow, then the land was divided into three blocks, leaving a distance of (2) meters between each blocks. After that, each blocks were divided into experimental units represented by panels with dimensions of (2 x 2) meters, numbering 24 experimental units. In each blocks, it was distributed into three irrigation levels in accordance with the number of factorial treatments for the factors involved in the experiment, which are (4 conditioner levels x 2 conditioner types x 3 irrigation levels), leaving a distance of 1 m between one experimental unit and another.

Table (1) Some primary physical and chemical characteristics of the study soil

Characteristics		Units	Depth (cm)		
			0 – 15	15-30	> 30
Ph		-	8.13	8.17	8.18
EC		dS m^{-1}	10.48	7.37	6.55
Pw at field capacity		%	31.30	31.80	32.40
Pw at saturation percentage			19.100	19.80	20.70
Sand		gm kg^{-1}	853.00	.83100	810.00
Silt			104.00	106.00	110.00
Clay			43.00	63.00	80.00
Texture		-	Sandy loam		
Partical density		µg.gm m^{-1}	2.63	2.64	2.65
Bulk density			1.59	1.61	1.62
Porosity		%	39.54	39.02	38.87
mean weight Diameter (MWD)		Mm	3.60	3.75	3.62
Saturalued hydraulic conductivity		cm h^{-1}	15.40	14.31	13.00
CEC		$Cmol^{+}kg^{-1}$	7.80	5.60	4.40
O.M		gm kg^{-1}	1.91	1.60	0.97
$CaCO_3$		gm kg^{-1}	137.00	128.00	116.00
Soluble ions	Ca^{+2}	mmol l^{-1}	17.20	16.40	15.25
	Mg^{+2}		7.90	8.40	6.80
	Na^{+}		28.15	26.33	23.80
	HCO_3		3.66	3.32	3.25
	CO_3		0	0	0
	Cl^{-1}		55.00	47.00	40.00
	SO_4		23.36	25.84	20.16

then, the factorial treatments were randomly distributed to the experimental units in each blocks using the factorial experiment in randomized complete block design (R.C.B.D), where all the conditioners added zeolite and vertisol soil at their levels to the surface of the soil, then mixed well to a depth of 0-30 cm. Then the barley grains, variety Ebaa 265, were planted on 21/11/2016. In the form of lines, with a distance of 20 cm between one line and another, then irrigation operations were carried out according to the irrigation factor levels, which are 60%, 80%, and 100%Ep, which is calculated from the American evaporation. US Pan class -A- with the addition of a 20% leaching requirement, provided that irrigation is repeated when the moisture content of the available water reaches 60% using a water irrigation system from an irrigation system, where the added water is controlled using valves for this. At the end of the experiment and before harvesting, the height of The plant, the length of the spike, the total grain yield, the weight of 1000 grains, and the water use efficiency for grain yield. The harvesting process was also conducted on 21/4/2017. The data was analyzed using the statistical program SPSS.

Table (2) Some physical and chemical properties of soil conditioners used in the experiment

conditioners characteristics	Units	Type of conditioners	
		vertisol	Zeolite
Ph	-	7.06	8.20
EC	ds m^{-1}	6.30	0.450
Pw at field capacity	%	66.30	45.20
Pw at saturation percentage		47.00	30.20
Sand	gm kg^{-1}	60.00	-
Silt		350.00	-
Clay		590.00	-
Practical density	µg.gm m^{-1}	2.65	2.61
Bulk density		1.30	1.36
Porosity	%	50.94	47.98

Main weight Diameter (MWD)		Mm	0.48	-
Satuvalued hydraulic conductivity		cm h^{-1}	0.60	10.00
CEC		$Cmol^{+}kg^{-1}$	42.80	22.30
O.M		gm kg^{-1}	6.40	0.86
CEC		gm kg^{-1}	280.14	60.30
Soluble ions	Ca	mmol l^{-1}	36	4.50
	Mg		34.50	3.22
	Na		20.70	2.25
	HCO_3		3.80	0.88
	CO_3		00	00
	Cl		84.00	18.30
	SO_4		11.47	3.60

Size distribution of diameters of zeolite particles						
Size range (mm)	< 0.25	0.25 – 0.5	0.5-1	1-2	2-4	>4
weight (gm kg^{-1})	234.87	191.74	191.79	192.43	159.71	29.46

3. Results and Discussion

Spike lengths

Table 3 show the Vertisols conditioner appeared higher and significant difference in spike length compared to zeolite conditioner with increase percent of 2.34%, this is attributed to the superiority of vertisol compared to zeolite in improving soil properties represent increasing available water , mean weight dimeter and decreasing bulk density, which improved root penetration, reducing the effort required for water and nutrient uptake, increasing photosynthetic efficiency and growing yield components.

The result in table 3 show significant effect of conditioner of level factor in spike length. The highest values were recorded at excessive level of the conditioner, in particular at the 3% level, with a widespread superiority compared to the other 0%,1%and 2% with increase percentage 8.01,4.69 and 1.52 %respectively.

Table (3): Effect of experimental factors and their interactions on barley spike lengths (cm)

Type of conditioners * Level of conditioners * Irrigation level				Type of conditioners		conditioners Level		Irrigation level	
Irrigation level	conditioners Level	vertisol	Zeolite	vertisol	Zeolite				
Ep 60%	%0	6.1	6.1	6.6	6.5	%0	6.3	Ep 60%	6.3
	%1	6.2	6.2						
	%2	6.3	6.3						
	%3	6.6	6.4			%1	6.5		
Ep 80%	%0	6.4	6.4					Ep 80%	6.7
	%1	6.8	6.5						
	%2	7.2	6.7			%2	6.6		
	%3	7.3	6.8						
Ep 100%	%0	6.3	6.3					Ep 100%	6.6
	%1	6.6	6.5			%3	6.8		
	%2	6.8	6.6						
	%3	6.8	6.8						
R.L.S.D 0.05	Ns			0.096		0.131		0.113	
conditioners Level* conditioners Type				conditioners Level* Irrigation level			conditioners Type* Irrigation level		
conditioners Level	vertisol	Zeolite		Ep 60%	Ep 80%	Ep 100%	Irrigation level	vertisol	Zeolite

%0	6.3	6.3	6.1	6.4	6.3	Ep 60%	6.3	6.2
%1	6.5	6.4	6.2	6.7	6.6	Ep 80%	6.9	6.6
%2	6.7	6.5	6.3	6.9	6.7	Ep 100%	6.6	6.5
%3	6.9	6.6	6.5	7.0	6.8	R.L.S.D 0.05	ns	
R.L.S.D 0.05	Ns		Ns					

The results in table 3 show the significant effect of irrigation level factor on the length of barley spikes. The irrigation level 80% Ep recorded the highest value of 6.7 cm, with a significant difference compared to the 60% Ep and 100% Ep level. Following that, the 100%EP irrigation level recorded 6.5 cm, which became considerably better than the 60% Ep level at 6.2 cm. This is attributed to the impact of the 80% Ep irrigation level in offering balanced conditions of moisture content, and different physical properties consisting of increasing porosity and decreasing bulk density compared to a 100% Ep irrigation level also lowering nutrient loss by leaching compared with 100% irrigation level (Singh et al., 2009). Table 3 shows that there is no significant effect of the possible two- and three-way interactions in the experiment on the lengths of ears at the end of the growing season.

Grain Yield

The results in table 4 show a significant effect of the conditioner type on grains yield. The Vertisol soil conditioner achieved the highest value with a significant superiority compared to the zeolite conditioner, this is due to the Vertisol conditioner providing optimum conditions for vegetative and reproductive growth as result of improving soil physical properties, and increasing soil moisture storage and increasing available water for plant. Water stress from moisture deficit significant reveres effect on growth and grain yield (Benmoussa and Achouch,2005).

Table (4) The impact of experimental factors and their interactions on barley grain yield values tons per Hectares.

Type of conditioners * Level of conditioners * Irrigation level				Type of conditioners		conditioners Level		Irrigation level	
Irrigation level	conditioners Level	vertisol	Zeolite	vertisol	Zeolite				
Ep 60%	%0	4.789	4.789	6.413	6.071	%0	5.167	Ep 60%	5.758
	%1	5.425	5.614						
	%2	6.372	6.002						
	%3	6.672	6.399						
Ep 80%	%0	5.187	5.187			%1	5.771	Ep 80%	6.488
	%1	5.757	5.747						
	%2	6.835	7.059			%2	6.706		
	%3	8.634	7.500						
Ep 100%	%0	5.525	5.525					Ep 100%	6.483
	%1	6.174	5.912			%3	7.327		
	%2	7.480	6.485						
	%3	8.115	6.644						
R.L.S.D 0.05	Ns			0.198		0.264		0.234	

conditioners Level* conditioners Type			conditioners Level* Irrigation level			conditioners Type* Irrigation level		
conditioners Level	vertisol	Zeolite	Ep 60%	Ep 80%	Ep 100%	Irrigation level	vertisol	Zeolite
%0	5.167	5.167	4.789	5.187	5.525	Ep 60%	5.814	5.701
%1	5.785	5.757	5.519	5.752	6.043	Ep 80%	6.603	6.373
%2	6.896	6.515	6.187	6.947	6.983	Ep 100%	6.824	6.141

%3	7.807	6.847	6.535	8.067	7.379	R.L.S.D 0.05	ns
R.L.S.D 0.05	0.435		0.590				

In addition to, there was a significant effect of conditioner level on grain yield, the highest increase percentage was at the 3% level, reach to 41.831%,29.790% and 11.711% compared with 0%,1% and 2% level, respectively. The increase in production is due to the role of conditioners in improving the physical properties of the treated sandy soil. Depending on the level of addition of the conditioner, including increased stability of the aggregates and decreased bulk density, as well as a decrease in the water conductivity of those soils, which reflected positively on the increase in the soil's ability to hold available water and the increase in the moisture content of the soil, which It was reflected in vegetative growth and reproduction growth in accordance with the level of addition (Al-Khadher, 2012; Hinsinger, 2001).

Table 4 also shows the significant effect of irrigation level on grain yield values , The irrigation level of 80%Ep achieved the highest value (6.488ton h-1) followed by 100% Ep level with (6.483 ton h-1) while 60% Ep recorded the lowest value (5.758 ton h-1) , this is due to the aforementioned reasons related to increasing the level of irrigation from 60% to 80% to 100% Ep, has increased the moisture content and the level of available water for the plant, which It increased vegetative growth, and reflected in increased production (Al-Alwani ,2005).

The results in table 4 show that there is a significant effect of the interaction between the type and level of the conditioner on grain yield values . It is clear that the significant increase in grain yield values for the Vertisol soil treatment compared to the zeolite treatment varies depending on the level of addition of the conditioner. The variance between these factorial treatment increases by increasing the level of addition from 1%, 2%, and 3%, and the highest significant differences appeared at the 3% level. This is due to the aforementioned reasons related to the multiple effective role of Vertisol soil conditioner compared to Zeolite conditioner in improving soil structure, increasing moisture content and available water, and reducing bulk density values. which is enhanced by increasing the level of addition in its effect on vegetative growth reproduction growth.

Weight of 1000 grains

The results in Table 5 show that there is a significant effect of the type of conditioner on the average weight of 1000 grains. The Vertisol soil conditioner achieved the highest weight of 1000 grains, with a significant superiority compared to the zeolite conditioner, with an increase percentage 2.575%.

Table (5) The effect of experimental factors and their interactions on the weight yield of 1000 barley grains (gm).

<table>
<tr><th colspan="4">Type of conditioners * Level of conditioners * Irrigation level</th><th colspan="2">Type of conditioners</th><th colspan="2" rowspan="2">conditioners Level</th><th colspan="2" rowspan="2">Irrigation level</th></tr>
<tr><th>Irrigation level</th><th>conditioners Level</th><th>vertisol</th><th>Zeolite</th><th>vertisol</th><th>Zeolite</th></tr>
<tr><td rowspan="4">Ep 60%</td><td>%0</td><td>39.177</td><td>39.177</td><td rowspan="10">44.455</td><td rowspan="10">43.339</td><td rowspan="3">%0</td><td rowspan="3">41.034</td><td rowspan="4">Ep 60%</td><td rowspan="4">42.089</td></tr>
<tr><td>%1</td><td>42.577</td><td>40.177</td></tr>
<tr><td>%2</td><td>44.550</td><td>40.877</td></tr>
<tr><td>%3</td><td>45.500</td><td>44.677</td><td rowspan="3">%1</td><td rowspan="3">42.944</td></tr>
<tr><td rowspan="4">Ep 80%</td><td>%0</td><td>40.750</td><td>40.750</td><td rowspan="4">Ep 80%</td><td rowspan="4">43.619</td></tr>
<tr><td>%1</td><td>43.810</td><td>42.777</td></tr>
<tr><td>%2</td><td>45.167</td><td>44.450</td><td rowspan="3">%2</td><td rowspan="3">45.070</td></tr>
<tr><td>%3</td><td>46.200</td><td>45.050</td></tr>
<tr><td rowspan="2">Ep 100%</td><td>%0</td><td>43.177</td><td>43.177</td><td rowspan="2">Ep 100%</td><td rowspan="2">45.982</td></tr>
<tr><td>%1</td><td>44.350</td><td>43.977</td><td>%3</td><td>46.538</td></tr>
</table>

	%2	46.527	48.850						
	%3	51.677	46.127						
R.L.S.D 0.05		2.037		0.491		0.727		0.630	

conditioners Level* conditioners Type			conditioners Level* Irrigation level			conditioners Type* Irrigation level		
conditioners Level	vertisol	Zeolite	Ep 60%	Ep 80%	Ep 100%	Irrigation level	vertisol	Zeolite
%0	41.034	41.034	39.177	40.75	43.177	Ep 60%	42.951	41.227
%1	43.579	42.31	41.377	43.293	44.163	Ep 80%	43.982	43.257
%2	45.414	44.726	42.713	44.808	47.688	Ep 100%	46.432	45.532
%3	47.792	45.284	45.088	45.625	48.902	R.L.S.D 0.05	ns	
R.L.S.D 0.05	1.264		Ns					

This is due to the role of the Vertisol soil conditioner in providing suitable and balanced conditions for vegetative and fruitful growth, compared to the zeolite conditioner in improving the physical properties of the soil. the most important of which is soil structure and increasing its ability to conserve moisture, which increased the water available to the plant, which in turn encouraged the distribution of the root system within soil profile. Which reflected positively on the productive characteristics of the plant represented by the weight of barley grains. Water stress represented by moisture deficiency has a significant effect on the decrease in grain yield and weight of 1000 grains. (Benmoussa and Achouch, 2005).

The results shown in table 5, it appears that there is a significant effect of the level of the conditioner on the weight of 1000 grains. The lowest values were recorded at 0% level, and the values increased significantly with the increase in the level of adding the conditioner. The 3% level achieved the highest values in the yield of 1000 grains, followed by the 2% level, then 1%, this is due to the role of the high moisture content and the available and optimal water level, which increased with the increase in the level of adding the conditioner, which enabled the plant to grow and complete its vital tasks as a result of increased photosynthesis and gave the highest grain yield at high levels of the conditioner (Gairley et al., 2015; Karbout et al, 2015).

The results in table 5 also show a significant effect of irrigation level on the yield of 1000 grains. The irrigation level of 100% Ep exceeded the levels of 80% Ep and 60% Ep, respectively, with a significant difference and an increase present of 5.417% and 9.249%, while the irrigation level of 80% Ep exceeded the irrigation level of 60% Ep, with an increase present of 3.635% , this is due to the decrease in tension exerted on the root system of the barley plant by increasing the level of irrigation as a result of the increase in water available to the plant, which facilitates the process of absorbing the necessary water and nutrients and increasing the turgor pressure, which increases vegetative and fruiting growth, as well as reducing the effort expended by the plant to absorb water and saving this effort in Increased vegetative production and fruit growth. The lack of available water during the grain-filling period negatively affects the amount of dry matter from the leaves to the stem and then to the grains (Al-Khader, 2016), (Medrano, 2002), and Liu et al., 2006).

The same results also show a significant effect of the interaction between the type and level of the conditioner on the yield values of 1000 grains, as it is clear that the significant increase in yield values for the Vertisol soil treatment compared to the zeolite treatment varies depending on the level of addition of the conditioner. The variance between the benefactors increases by increasing the level of addition from 1%, 2%, and 3%, and the highest significant differences appeared at the 3% level, the percentage of increase between these conditioners reached 2.999%, 1.538%, and 5.538% for the levels 1%, 2%, and 3. % respectively. When comparing the increase percentages for the Vertisol soil conditioner at the level of 3%, 2%, and 1% compared to the comparison level, they were 16.469%, 10.674%, and 6.202%, while the increase percentage for the zeolite conditioner for the same levels above was 10.357%, 8.997%, and 3.110%. straight. This is due to the multiple effects of Vertisol soil conditioner compared to Zeolite conditioner in improving soil structure and increasing the moisture content and water available for the plant. This is enhanced by increasing the level of addition in its effect on vegetative growth, which reflects positively on grain weight.

The results also show in Table 5 the significant effect of the triple interaction between irrigation level and the type and level of the conditioner on the 1000-grain weight values of barley seed yield, as it turns out that the highest yield values were recorded at the factorial treatments under the 100% Ep irrigation level and at high levels of the Vertisol soil conditioner, especially at the irrigation level 100% Ep.

Water use efficiency for grain yield

The results in Table 6 show that there is a significant effect of the conditioner type factor on the water use efficiency values of barley grain yield at the end of the growing season. The Vertisol soil conditioner achieved significant superiority in water use efficiency for grain yield, with an increase value of 4.796% for the Vertisol soil compared to the zeolite conditioner. this due to reasons related to the characteristics of Vertisol soil, represented by its high ability to storage water and improve the physical properties of the soil compared to the zeolite conditioner, which reflects positively on the efficiency of the barley plant in increasing the assimilation of nutrients to form the yield, including grain yield, and increasing the efficiency of water use.

Table (6) Effect of experimental factors and their interactions on water use efficiency of barley grain yield kg mm-1 m-2

Type of conditioners * Level of conditioners * Irrigation level				Type of conditioners		conditioners Level		Irrigation level	
Irrigation level	conditioners Level	vertisol	Zeolite	vertisol	Zeolite				
Ep 60%	%0	0.746	0.746	0.437	0.417	%0	0.353	Ep 60%	0.508
	%1	0.751	0.691						
	%2	0.780	0.827						
	%3	1.098	0.876			%1	0.396		
Ep 80%	%0	0.568	0.568					Ep 80%	0.430
	%1	0.614	0.628						
	%2	0.673	0.630			%2	0.459		
	%3	0.840	0.672						
Ep 100%	%0	0.477	0.477					Ep 100%	0.343
	%1	0.556	0.524			%3	0.501		
	%2	0.603	0.579						
	%3	0.748	0.651						
R.L.S.D 0.05		ns		0.015		0.018		0.016	

conditioners Level* conditioners Type			conditioners Level* Irrigation level			conditioners Type* Irrigation level		
conditioners Level	vertisol	Zeolite	Ep 60%	Ep 80%	Ep 100%	Irrigation level	vertisol	Zeolite
%0	0.353	0.353	0.423	0.343	0.293	Ep 60%	0.513	0.503
%1	0.396	0.396	0.487	0.381	0.320	Ep 80%	0.437	0.422
%2	0.470	0.447	0.546	0.460	0.370	Ep 100%	0.361	0.325
%3	0.530	0.471	0.577	0.534	0.391	R.L.S.D 0.05	ns	
R.L.S.D 0.05	0.037		0.040					

Table 6 shows a significant effect of the conditioner level factor on the water use efficiency values of barley grain yield at the end of the growing season. All levels of adding the conditioner achieved a significant increase in water use efficiency values for grain yield compared to the comparison level of 0%, and the highest values were recorded at the 3% level, the percentages of increase, reaching 41.926, 30.028, and 12.181% at the 3% levels. And 2% and 1% compared to the control treatment 0%, this is due to the improvement of the physical properties of the soil by increasing the level of adding the conditioner.

The results in Table 6 show that there is a significant effect of the irrigation level factor on the water use efficiency values of barley grain yield. The 60% EP irrigation level exceeded, with a significant difference, the 80% Ep and 100% Ep irrigation levels, with an increase value of 18.139 and 48.104%, respectively, while the 80% Ep level recorded an increase in water use efficiency values for grain yield amounting to 25.364% compared to the100% Ep level, this is due to the fact that increasing the irrigation level from 60%, then 80%, to 100% Ep is not accompanied by an increase in grain yield, this is due to reasons related to the genetic characteristics of the plant and the plant variety, as well as there is limited growth factors other than the moisture content factor, which limited a linear increase in production occurs, Compatible with increased irrigation level. Among these factors, Al-Sahuki et al., (2013) found that the effect of water deficit stress on plants varies in intensity depending on the stages of plant growth.

The results in Table 6 show that there is a significant effect of the interaction between the type and level of the conditioner on the water use efficiency values of grain yield at the end of the growing season. It is clear that the significant increase in water use efficiency values for grain yield for the Vertisol soil treatment compared to the zeolite treatment varies depending on the level of addition of the conditioner, this is due to the aforementioned reasons related to the multiple effective role of Vertisol soil conditioner compared to Zeolite conditioner in improving soil structure, increasing moisture content and available water, and reducing bulk density values, and this matter is enhanced by increasing the level of addition in its effect on vegetative growth and thus on grain yield per unit of water added.

Table 6 shows the significant effect of the interaction between the irrigation level and the conditioner level on the water use efficiency values of grain yield, the significant differences between irrigation levels in water use efficiency values for grain yield vary depending on the level of addition of the conditioner, the highest significant differences between the levels of addition of the conditioner were recorded at the irrigation level of 60%Ep, especially at the high level of addition of 3%, and the rest of the addition levels are for the same irrigation level above. These variations decrease as the irrigation level increases until the Ep level is 100%, with these variations remaining within the threshold of significant differences. The highest water use efficiency values were recorded at the Ep irrigation level of 60% and the addition level of 3%, while the lowest water use efficiency values were recorded when the comparison treatment was 0%. The irrigation level is Ep 100%. This is due to the fact that increasing the level of adding conditioners increased the values of water use efficiency. However, increasing the level of irrigation led to a decrease in the water use efficiency of grain yield for the aforementioned reasons related to increasing the irrigation level from Ep 60% to Ep 80% and then Ep 100. % is not accompanied by an increase in grain yield because the increase in irrigation level was a linear increase, while the response of grain yield is a non-linear response and follows the law of diminishing returns due to the presence of other growth factors that will limit the growth and production of the plant when one of the factors is available at an ideal level.

4. Conclusion

The findings of this study underscore the superior efficacy of vertisol as a soil conditioner in enhancing the growth, yield, and water use efficiency of barley cultivated in sandy soils, particularly when applied at higher levels. Compared to zeolite, vertisol consistently demonstrated significant improvements in key agricultural metrics such as spike length, grain yield, and water use efficiency. These results suggest that the use of vertisol could be a more effective strategy for improving agricultural productivity in arid regions, where soil degradation and water scarcity are major challenges. The implications of this research are substantial for sustainable agricultural practices, particularly in arid and semi-arid regions like Iraq. However, further research is warranted to explore the long-term impacts of vertisol application on soil health and crop performance, as well as its efficacy across different crop types and environmental conditions.

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