Enhancing Water Management and Soil Quality by Using Modified Zeolite

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ABSTRACT

Climatic changes, water constraint, and soil quality degradation, along with rising food demand, need for a more effective cultivation system. This study examined the role of natural zeolite (Z) and modified zeolite (thermal activated zeolite) (AZ) (300 - 400 ºC for 3 hours) in enhancing soil quality and growth of barley plant at four doses 0(d0), 100(d1), 200(d2) and 300 (d3) kg/fed at three irrigation water quantities Q1 (60%), Q2 (80%), and Q3 (100%) through field experiment. The results indicated that Z and AZ increased CEC of soil environment, available N-P-K and increase soil DTPA extractable of Zn, Cu and Mn, and decreased soil EC especially at modified zeolite (300kg/fed) at 80% of irrigation water (AZd3Q2) followed by (AZd2Q2) then, (AZd1Q2) treatment. Additionally, modified zeolite enhanced N-P-K uptake by barley grain where, the best percentages of increase observed were 26.18%, 39.72%, and 15.92% respectively for AZd3Q2 treatment. On the other hand, the modified zeolite (200kg/fed) at 80% of irrigation water (AZd2Q2) treatment was the best treatment for water consumption as it saved 539.1 cubic meters of irrigation water that could increase production by 40.7%. Thus economically, the study suggested that AZd2Q2 was the best treatment.

Keywords: Modified zeolite – soil quality –water management.

INTRODUCTION

One of the most widely utilized and studied clay minerals that can greatly aid in maintaining soil quality is the zeolite mineral. “Zeolite”, is Greek word means “boiling stones”. It is artificial or natural crystalline composed of aluminosilicates as a primarily component. The general zeolite formula is Me_2/n O. Al_2O_3. $xSiO_2$. yH_2O, where y is the water molecules number, x is the Si tetrahedron number, n is the atom charge, and Me is alkaline atom. It is occurring naturally as volcanogenic sedimentary mineral (Jeevika *et al.,* 2015). Zeolite is composed of a three-dimensional crystal lattice with loosely bonded cations that can be hydrated and dehydrated without changing the crystal structure (Ramesh and Reddy, 2011). The world's natural zeolites are mostly found in Asia, Europe, Africa, Australia, New Zealand, and the United States, where their deposits are extensive. There are many types of natural zeolite such as, chaba, zite, clinoptilolite, mordenite, and erionite, which have unique properties and may find use in industry (USGS, 2016). Natural and modified zeolites have been successfully used in a wide range of applications as low-cost adsorbents (Sulaiman *et al.,* 2020). Chen *et al.* (2000) discovered, that zeolite increased the availability of K^+ and Ca^{2+} and decreased the leaching of exchangeable cations, particularly K^+, due to improving the physical properties of soil. Natural zeolites' ion-exchange and sorption capabilities in the soil can be exploited to release nutrients gradually and uniformly while preventing their rapid removal (Perry and Keeling-Tucker, 2000). Moreover, zeolite can reduce soil acidity and soil irrigation water, because it can retain water molecules within its structure (Comin *et al.,* 1999). As well as, it can reduce the temperature oscillations, thus the use of zeolite is useful especially in arid and semi-arid region, where agriculture uses more than 80% of the water in arid and semiarid areas (Earth Science Division of CAS, 1998).

Zeolite is a hydrated alkaline aluminosilicate that is mainly employed to enhance soil quality and raise agricultural yields (Mumpton, 1999), consequently, using zeolite can help with certain needs, such as improving water retention and more efficient fertilizer use. As well, zeolite contains micronutrients as Zn, Mn, Cu and macronutrients such as N, K, Ca, Mg (Navrotsky *et al.,* 1995). In addition, zeolite can be used as a carrier to herbicide and pesticide (Molina, 2013).

The most common type of zeolite is clinoptilolite, which is the naturally occurring zeolites and most frequently employed in agriculture (Ramesh & Reddy, 2011 and Badora, 2016).

It was observed that the cation-exchangeable capacity of the soil was enhanced by the addition of clinoptilolite (Usman *et al.,* 2006 and Badora *et al.,* 2011). In addition, it has beneficial impacts on soil's physical and chemical characteristics, such as increase water-holding capacity and adsorption capabilities (Mumpton, 1999 and Micu *et al.,* 2005).

Zeolite can hold nitrogen and water in the soil, thereby improving nutrient availability and soil properties (Nasseem *et al.,* 2011; Szatanik-Kloc *et al*., 2021 and El-Ghamry *et al*., 2024). In study of Abd El-Azeiz *et al.* (2024) they found that higher nitrogen doses generally increased growth parameters, grain yield and grain quality attributes, however zeolite significantly enhanced these parameters even at lower nitrogen levels, when it incorporation in soil. As well, Zeolite

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improves soil properties by reducing water leaching, thus saving soil water for agronomic crops. Thus, it is often used as a water absorbent substance due to its high porosity and ability to trap water molecules within its pores. When zeolite comes into contact with water, it will absorb the water and hold it within its structure. Zeolite is one of the soil amendments which improves soil properties and saves soil water (Khalifa *et al.,* 2019 and El-Sherpiny *et al.,* 2020).

Wu *et al.* (2019) found that the application of zeolite improved the drought resistance of rice and improved water productivity by 8.9%. Ippolito *et al.* (2011) concluded that applying zeolite at rate of 22 Mg ha^{-1} increased corn weight in comparison to control. Nevertheless, when the zeolite application rate raised to 90 Mg ha^{-1}, there was a reduction in corn weight. This decrease was attributed to the higher sodium content in soil. El-Mahdy *et al.* (2022) found that the addition of zeolite improved all studied growth and production parameters for soybean plant under water deficit treatments, compared to the corresponding soybean plants grown on un-amended soil. Bernardi *et al.* (2010) found that addition of zeolite to the soil resulted in an enhancement of irrigation water use efficiency. This improvement was attributed to the increase in the soil's water holding capacity and its availability to plants.

Soil quality is “The ability of a particular type of soil to sustain productivity of plants and animals, preserve or improve the quality of the water and air, and to maintain human health and habitation within the bounds of a natural or managed ecosystem” (Williams *et al.,* 2020).

Calcareous soil represents more than 30% of the earth's land surface, which is prevalent in dry and semiarid regions (Wahba *et al.,* 2019). Elevated amount of $CaCO_3$ in calcareous soils is considered a big challenge to management these soils, where these soils face many problems as low availability of nutrients, decrease water flow and penetration through the soil layers (Taalab *et al.,* 2019).

Ras Suder soil is a calcareous soil and suffers from increase salinity, that decrease the absorption of water and nutrients by plant and thus reduce crop yield and soil quality. Because pores of natural zeolite are covered by organic and inorganic impurities, therefore chemical or physical activation must be done (Khairinal and Trisunaryanti, 2000). The objective of this study was investigation the role of natural and modified (thermal activated) zeolite on ameliorating quality of calcareous soil (Ras Suder area) under different water levels. These objects were achieved through using natural and thermal activated zeolite in field experiment and examine the role of zeolite on some chemical and physical properties of soil, as well the best water treatment in experiment, in addition to productivity of barley (*Hordeum vulgare* L.) plant.

MATERIAL AND METHODS

The study was conducted as experimental field in north Sinai Governorate Ras suder Station-Desert research center at lat. 29.62504° and long. 32. 713064° during the seasons of experiment the climate was as shown in Table (1).

Cultivation strategies:

In field Experiment**,** Barley plant was planted (*Hordeum vulgare* L.), which is a significant tolerant of salt - cereal crop that can be cultivated in a variety of soil, water, and climate conditions.

Clinoptilolit Zeolite which has typical formula of unit cell ((Na_4K_4) $(Al_8Si_{40}O_{96}).24H_2O$) (Dogan, 2003), was added to field experiment in two forms, natural zeolite (Z) and thermal activated zeolite (AZ) in four different rates 0.00 (d0), 100 (d1), 200 (d2), and 300 (d3) kg/fed, in addition to organic fertilizer (poultry manure) at rate 15 m^3/fed to all treatments. Three irrigation quantities (ETm) were obtained from the product of the potential evapotranspiration (ETo) by crop coefficient for Barely at every stage then multiplying by 0.6, 0.8 and 1.0 for Q1 (1617.3 m3/f), Q2 (2156.4 m3/f) and Q3 (2695.5m3/f), respectively. The ETo were calculated from Penman-Monteith equation (Allen *et al.,* 1998). Drip irrigation system was applied. Water consumptive use was calculated using the following equation of Israelson and Hansen (1962).

$$CU= ((M2-M1) \times dp \times D) \div 100$$

Where:

CU = Consumptive use (mm). Such CU is an estimate of actual evapotranspiration of the crop i.e. actual ET crop.

D = Depth (in mm) of the irrigated soil under consideration.

dp = Bulk density (g/cm^3) of the soil in the relevant soil depth.

M2 = Percentage of moisture in soil (w/w) following maximum irrigation within the relevant soil depth.

M1 = Percentage of soil moisture (w/w) before next irrigation (within the relevant depth).

Soil moisture content was gravimetrically determined for 3 depths; 0-20, 20-40 and 40-60 cm, immediately before and after 24 hours of irrigation.

The actual evapotranspiration (ETa) for each stage as well as for the total season were determined. (WUE), kg/m^3 was calculated by dividing the crop yield by the amount of seasonal evapotranspiration (Giriappa, 1983).

Zeolite preparation and characterization

Natural zeolite was Clinoptilolite which is the most prevalent and well-researched one because of its greatest natural abundance, lowest cost, and broadest range of physicochemical characteristics (Pitcher *et al.,* 2004). In this study raw and modified (thermal activated zeolite) are used. The activation was done after being the zeolite was cleaned with distilled water and allowed to dry for two hours at 105 °C in an oven. The activation was done at around 300 ºC- 400 ºC for 3 hours then it conditioned for two hours in a desiccator to create the heat-activated zeolite (Kurniasari *et al.,* 2011). Elemental composition of raw and thermally activated zeolite were determined. In addition to, pH, CEC and SSA that determined by (BET) analyzer (Table 2). Scanning Electron Microscope (SEM) was used to identify surface and structural morphology of zeolite by using High resolution, analysis experiments that were carried out on a FEI Quanta FEG 250 instrument Figurer 1 (a, b). Powdered samples of raw and activated zeolite had been subjected to X-ray diffraction (XRD) by Using X-Ray Diffraction Test Instrument BRUKER, D2 PHASER 2nd gen Cu-radiation, the XRD patterns of both raw and activated zeolite were shown in Figure (2). The scan range for the diffract gram was within 2θ range of 5–80° with a step size of 0.02° and 0.2 second.

Soil characterization and water analysis

Some chemical and physical properties of Ras Suder soil was determined before experiment Table (4). pH and EC (electrical conductivity) of soil were determined in 1:1 (v/w) soil extraction (Black, 1965). By sodium acetate method CEC was determined. Soil organic matter was determined according to Walkley and Black (1934) method. Additionally, Collin's calcimeter was used to calculate the total carbonate equivalent. The Pipette technique was used to analyze the particle size of the fraction less than 2 mm (FAO, 1970). Some chemical analysis of irrigation water was done according to Page *at al.* (1984) (Table 5). Water consumptive use, the soil moisture content was gravimetrically determined at 3 depths; 0-20, 20-40 and 40-60 cm, immediately before and after one day of irrigation. The actual evapotranspiration (ETa) for each stage as well as for the total season were determined, crop coefficient was calculated for each stage of growth e according to Allen *et al.* (1998), Crop Water Use Efficiency.

Assessment of Soil Quality

After plant harvest, numerous indices of soil quality, such as pH, electrical conductivity (EC), and CEC, were measured in the soil. In addition to, some micronutrients (Mn, Zn, and Cu) were determined using the methodology outlined by Lindsay and Norvell (1978), then measured by using ICP (Inductively Coupled Plasma-Mass Spectrometry). Available NPK were determined. 2M potassium chloride solution was used to extract the available nitrogen, where Dhank and Johnson's (1990) methodology was followed. Soltanpour (1991) technique was used to quantify the amount of potassium and phosphorus that were available.

Plant analysis

Barley grains were washed with tap water then with distilled water for three times, after that it has been dried and grinded then some macro nutrients (N-P-K) was determined in grain according to Cottenie *et al.,* (1982). In addition to determine crop productivity of barley (*Hordeum vulgare L.*).

RESULTS AND DISCUSSION

Zeolite characterization

Scanning electron microscopy (SEM) is used for recognizing zeolites. Figure 1 (a, b) showed the SEM image of Z and AZ. It was obvious that image in Figure 1 (a) suggested, that there were clusters caused by particle agglomeration that vary in size and form. Many different shapes of crystal are shown as octahedral and cubic crystals, in addition to extremely smooth surface. After thermal activation relocation of crystals are happened and more pores are formed that might be due to lose of impurities and reduction in the number of interconnected water molecules inside the structure. These results were compatible with results obtained by Abdul Aziz *et al.* (2020). Likewise, pore diameter is significantly changed as a result of thermal activation due to cations movement (Wasielewski *et al.,* 2018).

Elemental analysis of the Z and AZ samples with smaller particle sizes (<0.5 mm) obtained via energy-dispersive X-ray analysis (EDX), Table (2) indicated a Si/Al mass ratio >4 and amounts, in grams, of Na + K > Ca, which is specific to clinoptilolite-type zeolite (Bish and Boak, 2001). The contents of major elements did not significantly change across the activation temperature, the most major elements show increase in concentrations, probably due to the loss of organic carbon from the sample. The data in Table (2) demonstrated that there were improve in CEC of zeolite after thermal activation where the value increased from 156.17 to 250.43 cmol/kg. SSA also increased due to thermal activation where it was 25.28 m^2/g for Z and become 70.57 m^2/g for AZ due to cracks and fragmentation that formed after activation (Wibowo *et al.,* 2016).

The XRD pattern of raw zeolite Figure 2 (a, b) showed that the material was mainly composed of Clinoptilolite-Na $((Na, K, Ca)_6(Si, Al)_{36}O_{72}\cdot 20H_2O$ (53.7%), with a presence of Heulandite-Ca

($CaAl_2Si_7O_{18}\cdot 6H_2O$) (47.3%), Figure 2 (a,b). Two major peaks at 9.8 and 22.14 (2Ө) were corresponding to clinoptilolite for both normal and thermal activation zeolites. So there was no difference in the crystallinity of zeolite as mentioned by Cerjan-Stefanović *et al.* (1996) and Perić *et al.* (2004) this due to that zeolite has high Si/Al ratio and thus great thermal stability. Results of XRF analysis in Table (3) Showed that SiO_2, Al_2O_3 and CaO are the main components and Na, K, Ca and Mg are the main cations these results are in agree with the results mentioned by Mansouri *et al.* (2013). During ignition of normal and thermal activated zeolite, CO_2 and water from clay minerals were lost by percentage13.69 and 17.65 % respectively. The Si/Al ratio was also calculated from XRF results for normal and thermal activated zeolite (5.29 and 5.50) these values are typical of clinoptilolite whose Si/Al ratio typically ranged from 4 to 5.5 (Çulfaz and Yağız, 2004).

Table 1. Average of climatic data at Ras Suder south of Sinai during months of experiment as stated by the Climate Institute of Egypt

Month	Prc.	Temp. max.	Temp. min.	Rel. hum.	Wind speed
	mm/m	°C	°C	%	m/s
Dec	5	19.6	14.5	58.1	4.3
Jan	1	19.2	13.2	61	4.2
Feb	12	19	13.1	62.7	4.7
Mar	0	21.5	14.3	54.9	5.2

Table 2. Some characteristics and elemental composition of natural zeolite (Z) and thermal activated zeolite (AZ) expressed as (%w/w)

Elements	Z (%)	AZ (%)
O	60.40	62.60
Si	24.40	24.50
Al	5.20	5.10
Ca	2.00	1.80
K	2.10	2.20
Fe	0.90	0.80
Mg	0.80	0.70
Na	0.50	0.50
Others	3.70	3.60
Other characteristics		
PH	8.85	7.97
CEC (cmol/kg)	156.17	250.43
SSA (m^2/g)	25.28	70.57

Table 3. The chemical composition of natural zeolite (Z) and thermal activated zeolite (AZ) as results of XRF analysis

Main constituents	Z (wt.%)	AZ (wt.%)
SiO_2	65.14	65.42
TiO_2	0.09	0.09
Al_2O_3	12.32	11.89
Fe_2O_3	1.64	2.03
MnO	0.03	0.04
MgO	1.06	0.78
CaO	3.88	2.45
Na_2O	3.19	1.15
K_2O	2.35	2.58
P_2O_3	0.04	0.03
SO_3	0.06	0.03
Cl	0.01	0.01
LOI	13.69	17.65
Si/Al ratio	5.29	5.50

LOI = loss on ignition

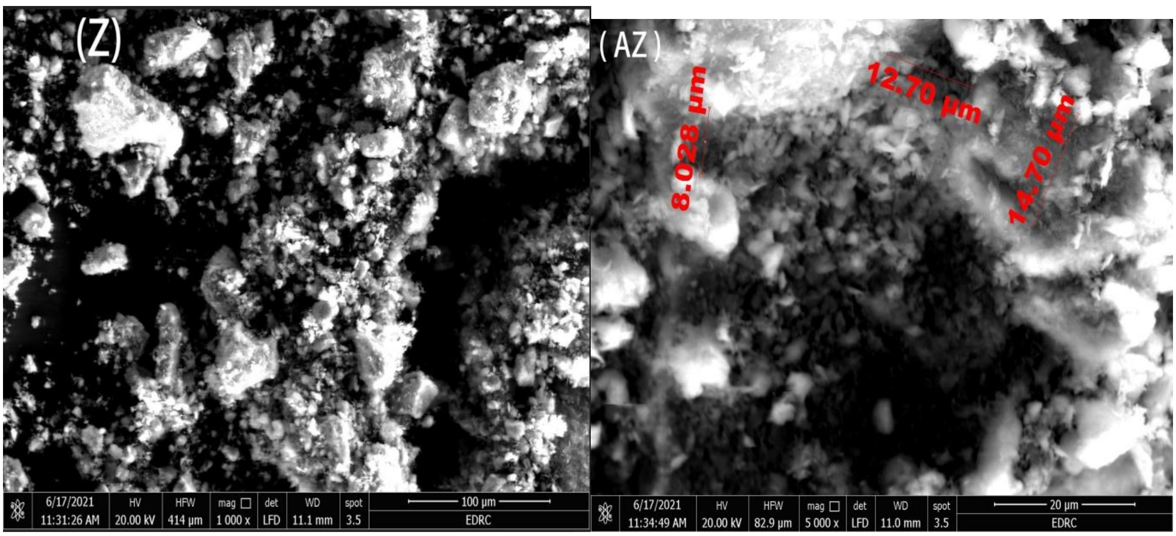

Fig. 1 (a and b) Scanning electron micrograph (SEM) of natural zeolite (Z) and thermal activated zeolite (AZ)

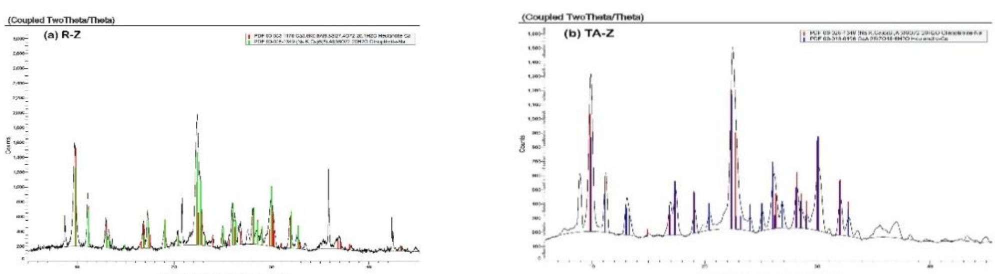

Fig. 2 (a, b) XRD pattern of natural zeolite (Z) and thermal activated zeolite (AZ)

Table 4. Some chemical and physical characterization of soil

pH 1:1	EC (dS/m) 1:1	O.M %	$CaCO_3$ (%)	CEC cmolc/kg	SAR	ESP %	Sand %	Silt %	Clay %	Texture
7.16	18.6	1.48	26.36	9.59	31.12	30.86	58.1	28.8	13.1	Sandy loam

Table 5. Some chemical analysis of irrigation water

Properties	
pH	8.20
EC (dS/m)	14.67
TDS (ppm)	9388.80
O.C (%)	0.134
SAR	20.28
ESP (%)	22.27
Soluble cations (mmolc/l)	
Ca^{2+}	39.80
Mg^{2+}	27.44
Na+	117.60
K^+	0.98
Soluble anions (mmolc/l)	
CO_3^{2-}	-
HCO_3^-	12.36
Cl^-	118.00
SO_4^{2-}	54.09

Assessment soil quality after addition natural and thermal activated zeolite at different water treatments

Soil pH

pH was measured in post-harvest soil samples. The data in Figure (3) demonstrated that pH slightly significant increased after zeolite addition compared to control (Table 6) at all different water treatments. The least increase in pH was recorded at Q2 (80% irrigation water quantity), where the percentage of increases were 0.14%, 0.41% and 1.37% for d1, d2 and d3 of zeolite doses, respectively. Thus, pH was affected by amount of zeolite. This might be due to alkaline properties of zeolite (Ippolito *et al.*, 2011), where its pH was 8.85 (Table 2). In addition to H^+ in solution takes the place of K^+ or NH_4^+ in zeolite pores, thus pH of soil solution increased. These results were insured by Li *et al.* (2009) and Suradkar *et al.* (2023) who observed increase in soil pH value with increase zeolite rate. However, Karami *et al.* (2020) found that there was no significant impact of zeolite on soil pH. As well, there were slightly significant increase in pH values in case TZ compared to Z treatment. This increase due to increase numbers of pores which are formed after thermal activation due to lose of impurities and thus more H^+ get into these pores. The study may argue the slightly increase in pH to the addition of organic fertilizer which biodegraded under field condition and offset the high increase in pH values. Interaction between irrigation treatment x zeolite doses showed slight significant effect.

Table 6. pH, EC, and CEC values in soil treated by zeolite and activated zeolite at 3 different water treatment

Water treatment	Zeolite doses	pH 1:1		EC dS/m 1:1		CEC cmolc/kg	
		Z	AZ	Z	AZ	Z	AZ
Q1							
	d0	7.26d	7.26d	17.16c	17.16cd	8.84e	8.84f
	d1	7.37c	7.31cd	17.23c	16.87d	9.12d	9.67e
	d2	7.45b	7.37c	16.69de	16.65d	10.08c	10.82d
	d3	7.54a	7.59a	16.96d	16.01e	11.16b	11.32cd
Q2	d0	7.32cd	7.32cd	17.71b	17.71b	9.21d	9.46e
	d1	7.33c	7.39c	17.57bc	16.46d	9.95c	10.48de
	d2	7.35c	7.42b	16.98d	16.62d	10.57b	11.38cd
	d3	7.42b	7.46b	16.86d	15.99e	11.55ab	12.96b
Q3	d0	7.17e	7.17e	18.08a	18.08a	9.57cd	9.49e
	d1	7.24d	7.32cd	17.90b	16.99cd	10.25b	11.07d
	d2	7.29cd	7.44b	17.13c	16.70d	11.12ab	11.99c
	d3	7.32c	7.55a	16.98cd	16.55d	11.92a	13.57a
$LSD_{0.05}$							
Z.T		0.012	0.010	0.261	0.346	0.005	0.407
W.T		0.011	0.008	0.226	0.300	0.004	0.353
WXZ		0.022	0.017	NS	NS	0.008	NS

Q1, Q2, Q3: 60%, 80% and 100% of irrigation water, respectively - d0, d1, d2 and d3: 0, 100, 200 and 300 kg/fed zeolite or activated zeolite - Each value is an average of three replicates. Least significant differences (LSD) at P < 0.05. Same letters within a column indicated there was no significant difference according to the Duncan test at P < 0.05

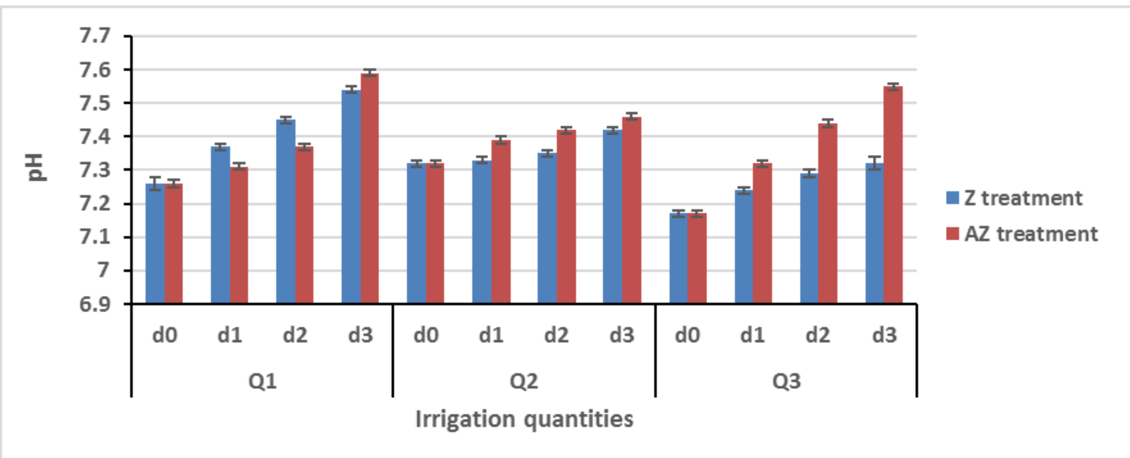

Fig. 3. pH values of soil treated by Z and AZ at 3 different water treatments (Q1, Q2and Q3)

Electrical conductivity EC

Figure (4) showed that EC was significantly decreased (Table 6) in soil after zeolite addition. For instance, at Q2 water treatment, EC was 17.71 ds/m in control treatment (d0) and decreased to 17.35, 17.05, and 17.01 ds/m in d1, d2, and d3 for Z treatments, respectively. In all water treatments, the reduce in EC value was recorded in soil treated with high zeolite dose. That may be due to the negative charge found on zeolite which generated by the presence of AlO^{2-} and stabilized by cations as Na^+ in addition to; zeolite has a large surface area for containing and exchanging vital nutrients due to its open structure with a crisscross pattern of pores (Munir *et al.*, 2024). Zeolite has ability to adsorb sodium ions and trapped them in its cavities that could improve soil salinity. These results were insured by Bybordi (2016). Additionally, Noori *et al.* (2006) reported that natural zeolite clinoptilolite has ability to decrease soil salinity.

The decrease in EC for soil treated by AZ was higher than in soil treated by Z as shown in Figure (4), that might be due to increase CEC of AZ than Z (Table

2). In addition, no significant effect between interaction water treatments x zeolite doses was observed.

Cation exchange capacity CEC

According to results of study, zeolite addition to soil significantly increased CEC of soil environment (Table 6 and Figure 5). At Q2 water treatment has the highest percentage of increasing CEC value of soil environment that was recorded (23.73%) at Zd3 treatment, while the lowest increasing (6.59%) was recorded at d1 for zeolite treatment, therefore the CEC value increase by increasing dose of zeolite added to soil. These results were observed by Badora *et al.* (2011); Ozbahce *et al.* (2015) and Suradkar *et al.* (2023). These increases might be attributed to high CEC of zeolite due to its unique pore structure as shown in Figure (1a). It has cages with a diameter of around 12 Å make up this pore structure, which is joined by channels with a diameter of roughly 8 Å. These channels are composed of 12 interconnected tetrahedron rings (Kaduk and Faber, 1995). In addition to, the presence of organic fertilizers, which contributes to increase CEC of soil environment due to release some compounds such as lignin that can adsorb cations from soil solution (Lima *et al.*, 2009). Similar results were obtained by Kalita *et al.* (2020) who discovered that adding composted manure and clinoptilolite zeolite enhances soil physical characteristics including soil CEC.

If we compare between Z and AZ, the data demonstrated that the increase in CEC of soil environment was significantly higher in case AZ than in Z at the same zeolite dose in all water treatments. For example, at Q2 water treatment the date showed at AZd3 that the percentage of increase was 38.83% while in Zd3 was 23.73%. These results might have attributed to removal of organic impurities from zeolite structure due to the thermal activation process which also increase number of pores and pore diameter (Purbaningtias *et al.*, 2017) as shown in Table (2). On the other hand, for interaction between different water treatments x zeolite doses has no significant effect on CEC values (Table 6).

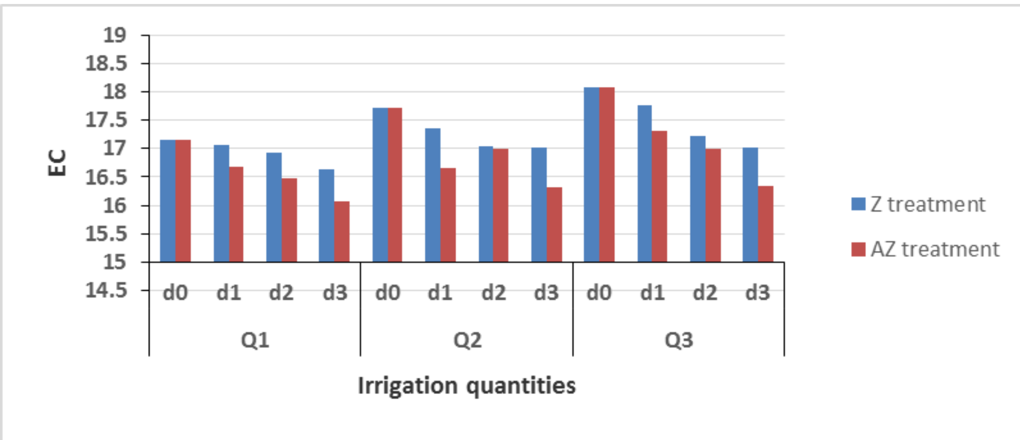

Fig. 4. EC values of soil treated by Z and AZ at 3 different water treatments Q1, Q2 and Q3

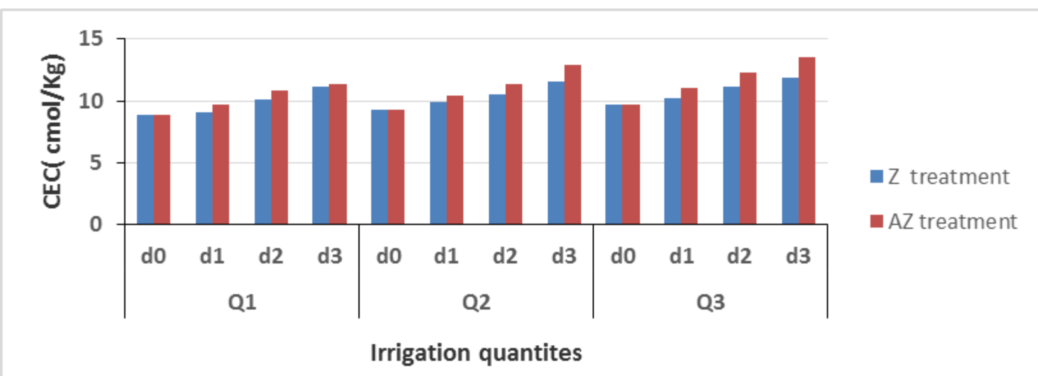

Fig. 5. CEC values of soil treated by Z and AZ at 3 different water treatments

Table 7. Average values of available NPK in soil treated by Z and AZ at 3 different water treatments

Water treatment	Zeolite doses	N(mg/g)		P(mg/g)		K(mg/g)	
		Z	**AZ**	**Z**	**AZ**	**Z**	**AZ**
Q1	d0	206e	206e	6.68d	6.68d	92f	92f
	d1	217d	228d	6.93cd	7.41b	133e	159d
	d2	221cd	242cd	7.71bc	7.71ab	166d	207c
	d3	228c	249cd	7.83b	7.93a	194c	235ab
Q2	d0	226c	226d	7.19c	7.19c	98f	98f
	d1	256ab	277c	7.71bc	7.41b	187cd	199d
	d2	266a	295b	7.89b	7.71ab	211bc	235b
	d3	270a	315ab	8.19a	8.04a	232a	246a
Q3	d0	244b	244cd	6.42e	6.42	102	102e
	d1	256ab	302b	6.53d	7.17c	179cd	205c
	d2	263a	323ab	6.66d	7.39b	221b	239ab
	d3	274a	337a	6.84b	7.46b	237a	246a
LSD $_{0.05}$							
Zd		0.586	0.723	0.083	0.079	0.253	0.821
Q.T		0.677	0.835	0.096	0.091	0.292	0.948
ZXQ		1.172	1.445	0.166	0.158	0.505	1.642

Q1, Q2, Q3: 60%, 80% and 100% of irrigation water, respectively - d0, d1, d2 and d3: 0, 100, 200 and 300 kg/fed zeolite or activated zeolite - Each value is an average of three replicates. least significant differences(LSD) at $P < 0.05$. Same letters within a column indicated there was no significant difference according to the Duncan test at $P < 0.05$

Available NPK

For available nitrogen and potassium, the data showed that there was significant increase in soil available nitrogen and potassium (Table 7 and Figure 6), due to increase the dose of zeolite added to soil. In soil treated with natural zeolite the percentage of available N increased by 13.30%, 17.96% and 19.51% for Zd1%, Zd2 % and Zd3 % zeolite treatment respectively, compared to control (Zd0) at Q2 irrigation water amount. The percentage of available K increased by increasing the dose of zeolite as follow, Zd3 (137.90%) > Zd2 (115.74%) > Zd1 (91.17%). Zeolite decreased the leaching of nitrogen and K due to its large porosity and special structure that facilitate enter and exit ions, in addition to its selectivity to ammonium and potassium ions, this result was mentioned by Torma *et al.* (2014); Baghbani-Arani *et al*. (2021) and Ravali *et al*. (2021). Likewise, the presence of organic fertilizer provided soil with N and K. Zeolite partially prevents the nitrification process and decrease nitrate leaching as mentioned by Lija *et al.* (2014) and Waldrip *et al.* (2014). Thus zeolite storage, collection and delayed release of nitrogen and potassium as mentioned by Ravali *et al.* (2021) who found that zeolite increase availability of N and K in incubation experiment in alkaline loamy sand soil because it reduces losses and leaching of these elements. As well, Tallai *et al*. (2017) observed significantly increase in available N, P and K after soil treatment with zeolite.

By comparison between Z and AZ treatments the percentage of increase for available nitrogen was higher in soil treated with thermal activated zeolite than in soil treated with natural zeolite where the percentage of increase 22.61%, 30.59% and 39.69% for AZd1%, AZd2 % and AZd3 %, respectively, compared to control AZd0 at Q2 water treatment. Likewise, for available potassium the percentage of increase was higher in AZ than for Z treatment, where it increased by 104.28%, 141.26% and 151.73% for AZd1, AZd2 and AZd3, respectively. These results could be attributed to increase CEC of soil environment after addition thermal activated zeolite, that have high CEC and SSA values (Table 2). In the same vein the percentage of increase differed with various irrigation amount of water, where the treated soil with natural and thermal activated zeolite at Q2 irrigation water amount had the highest amount of available nitrogen followed by Q3 then Q1.

For available phosphorus the percentage of increase after zeolite addition was low compared to available potassium. At Q2 water treatment, the percentage of increase in available p was as follow Zd1 (7.31%), Zd2 (9.81 %), and Zd3 (13.99 %) thus, available P significantly increased by increasing the rate of zeolite in soil (Table 7). This may be due to alkaline nature of zeolite and presence of negative charge, that reduce soil available Fe, and Al ions thus, decrease P fixation by metal oxy hydroxides as mentioned by Allen *et al.* (1993) and Shokouhi *et al.* (2015) similar observation was reported by Zheng *et al.* (2019) who found, that clinoptilolite zeolites increase availability of P in soil. By comparison between Z and AZ treatments there were slightly significant change, likewise, in different water treatments. Furthermore, the interaction between water treatment x zeolite doses was significant.

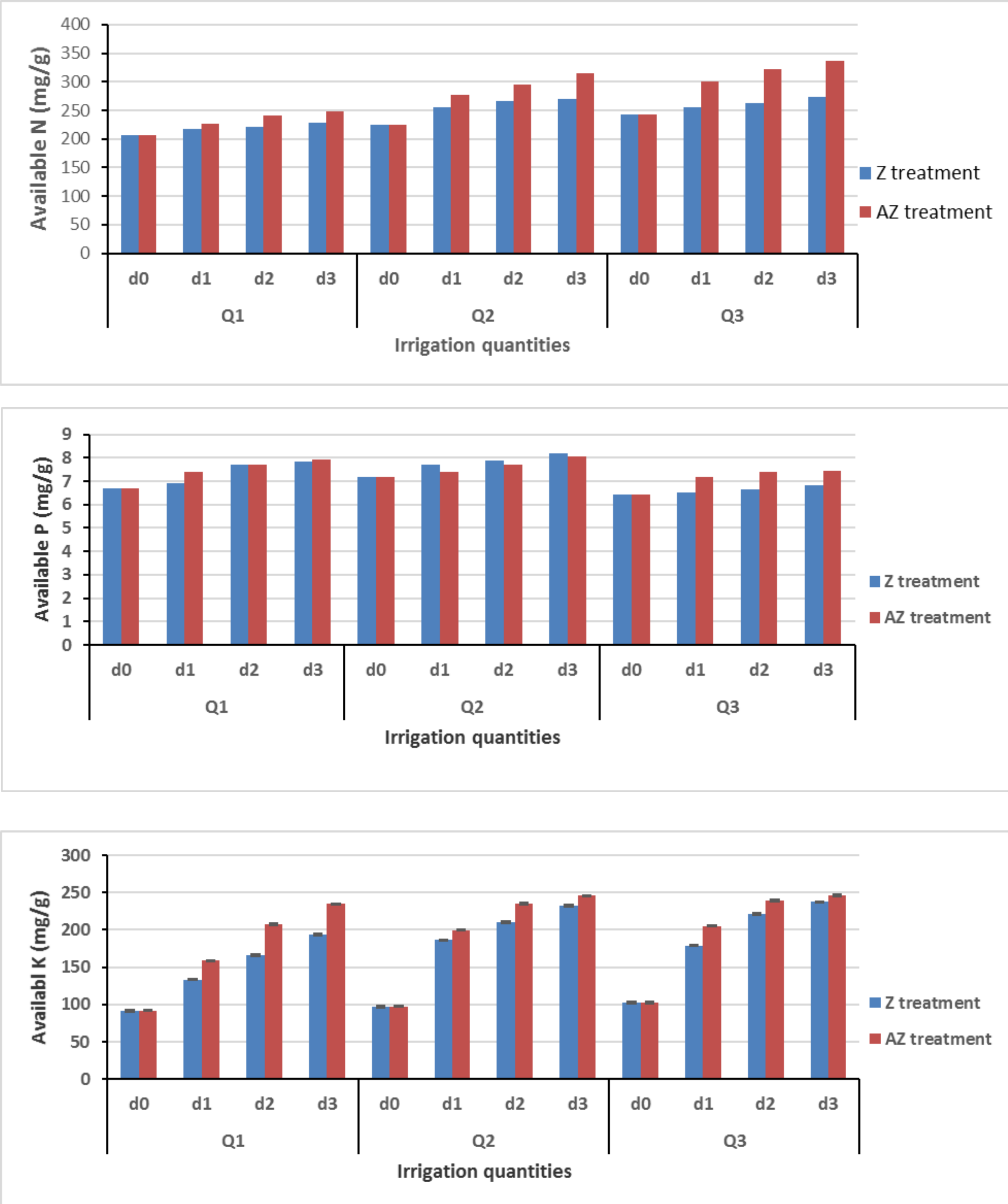

Fig. 6. Available NPK values of soil treated by Z and AZ at 3 different water treatments Q1 (60%), Q2 (80%) and Q3 (100%) DTPA extractable of Zn, Cu, and Mn

Table (8) showed average values of DTPA extractable of Zn, Cu, and Mn in soil after and before soil treatment by two forms of zeolite at three different irrigation treatments. The data demonstrated that the addition of zeolite significantly increased the amount of DTPA extractable Zn compared to control. At Q2 of irrigation water treatment, the percentage of increase in DTPA extractable of Zn was 7.25%, 17.79% and 32.45 % for zeolite doses Zd1, Zd2, and Zd3, respectively. As well there was significant increase in DTPA extractable copper in soil amended with zeolite compared to control. The percentage of increase was 4.65%, 10.30%, and 28.57 % for Zd1, Zd2, and Zd3 doses, respectively, at Q2 water treatment. Therefore, increase zeolite dose has a positive effect on DTPA extractable of copper. Furthermore, the DTPA extracted Mn increased significantly after zeolite addition compared to control. The percentage of increase in DTPA extracted of Mn was as follow. 24.37%,40.49%, 53.51% for Zd1, Zd2, and Zd3 respectively at Q2 water treatment. At different irrigation water treatments, the effect of zeolite doses on DTPA extracted of Mn was more obvious (Figure 7). Thus DTPA extractable Zn, Cu and Mn increased due to increase zeolite dose especially, in the present study of where the presence of organic fertilizer enriches the soil by different nutrients. These results are in agreement with Kavvadias *et al.* (2023) who demonstrated, that Clinoptilolite zeolite could adsorb different cations as Zn, Mn, Cu which exists in readily available fractions due to its high CEC and SSA in alkaline soils. In addition, Restiawaty *et al.* (2024) demonstrated that zeolites can adsorb cations because of the negative charges on their surface.

On the same vein, addition of thermal activated zeolite to soil increased DTPA extractable Zn, Cu and Mn depending on doses of zeolite. At Q2 irrigation water treatment, Zn DTPA extractable increased significantly by addition AZ compared to Z at the same zeolite dose, where the percent of increase was 22.90%, 35.58% and 44.48% at AZd1, AZd2, and AZd3, respectively. The percentage of increase in DTPA extracted Cu was recorded as follow 7.97%, 22.26% and 26.91% for AZd1, AZd2, and AZd3, respectively. At the same water treatments DTPA extracted Mn was 33.36%, 42.27% and 55.68% for AZd1, AZd2, and AZd3, respectively. These findings due to increase CEC of activated zeolite-treated soils (Suradkar *et al.*, 2023). In addition, the results demonstrated that the interaction between water treatments x zeolite doses has a significant effect on DTPA extractable Zn, Cu and Mn. The study could interperate this positive interaction to increase microbial activity, which accelerate the biodegradation of organic fertilizers in zeolite- treated soil. Furthermore, after thermal treatment of zeolite, the empty pores could be filled with water molecules or adsorbates (Kuldeyev *et al.*, 2023).

Table 8. Average values of DTPA extracted Zn, Cu and Mn in soil treated by zeolite and activated zeolite at 3 different water treatments

Water treatment	Zeolite doses	Zn (mg/kg)		Cu (mg/kg)		Mn (mg/kg)	
		Z	AZ	Z	AZ	Z	AZ
Q1	d0	5.21f	5.21g	2.66de	2.66f	23.62g	23.62h
	d1	5.41ef	7.20d	2.61de	3.22de	27.25f	30.81f
	d2	6.31cd	7.65c	2.77d	3.35d	30.07e	34.93e
	d3	6.57c	7.95bc	2.92c	3.58cd	32.34d	38.39c
Q2	d0	6.27d	6.27e	3.03c	3.03e	26.01f	26.01g
	d1	6.64b	7.63c	3.23bc	3.32d	32.10d	34.52d
	d2	7.38bc	8.40b	3.35b	3.75c	36.59b	36.79cd
	d3	8.24a	8.84	3.84ab	3.84ab	39.62a	40.31
Q3	d0	5.71e	5.71f	3.33b	3.33d	27.55f	27.55g
	d1	6.45c	7.85bc	3.47b	3.78c	31.60d	33.42d
	d2	6.56c	8.61ab	3.90ab	3.97b	33.29c	41.52b
	d3	7.50b	8.85a	4.11a	4.58a	38.23a	43.71a
LSD $_{0.05}$							
Zd		0.257	0.111	0.089	0.0423	0.324	0.386
Q.T		0.222	0.096	0.077	0.037	0.281	0.335
ZXQ		NS	0.192	0.154	0.0733	0.561	0.669

Q1, Q2, Q3: 60%, 80% and 100% of irrigation water, respectively - d0, d1, d2 and d3: 0, 100, 200 and 300 kg/fed zeolite or activated zeolite - Each value is an average of three replicates. Least significant differences (LSD) at $P < 0.05$. Same letters within a column indicated there was no significant difference according to the Duncan test at $P < 0.05$

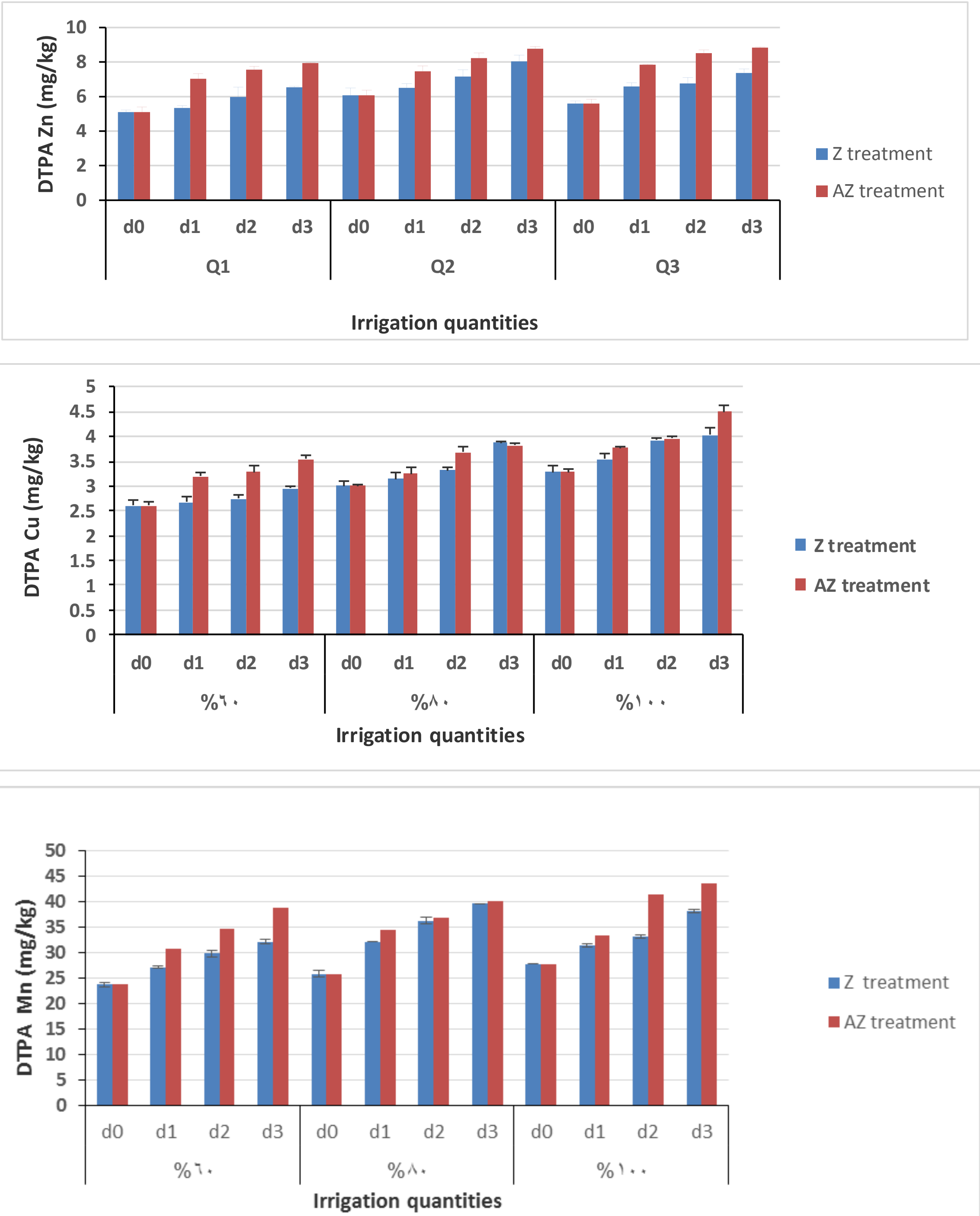

Fig. 7. DTPA extracted Zn, Cu and Mn in soil treated by RZ and AZ at 3 different water treatment

Table 9. NPK in grains of barley plant grow in treated soil by zeolite and activated zeolite at 3 different irrigation treatments

Irrigation Treatment	Zeolite doses	N(mg/g)		P(mg/g)		K(mg/g)	
		Z	AZ	Z	A Z	Z	AZ
Q1	d0	27.35f	27.55g	2.275i	2.256f	5.436f	5.455h
	d1	28.55e	29.55f	2.565h	2.879e	5.674e	5.868g
	d2	28.99e	31.55e	2.874g	2.957e	5.883d	6.036f
	d3	29.55d	33.25d	2.998g	3.224de	5.926d	6.173e
Q2	d0	29.69cd	29.73f	3.635f	3.518d	6.355c	6.346d
	d1	32.09bc	33.95d	4.015e	4.426c	6.574c	6.675c
	d2	33.58bc	36.68b	4.293cd	4.835b	6.653bc	7.155bc
	d3	34.68b	37.48ab	4.538c	4.997b	6.975b	7.361b
Q3	d0	30.39c	30.53e	4.523c	4.516c	7.502a	7.514ab
	d1	33.56bc	34.39c	4.735c	4.833b	7.571a	7.604ab
	d2	34.39b	36.48b	5.034b	5.136ab	7.663a	7.692a
	d3	36.46a	38.39a	5.255a	5.468a	7.666a	7.722a
$LSD_{0.05}$							
Zd		0.163	0.063	0.383	0.056	0.137	0.215
Q.T		0.141	0.121	0.331	0.049	0.119	0.186
ZXQ		0.282	0.182	0.663	0.098	0.238	0.373

Q1, Q2, Q3: 60%, 80% and 100% of irrigation water, respectively - d0, d1, d2 and d3: 0, 100, 200 and 300 kg/fed zeolite or activated zeolite - Each value is an average of three replicates. Least significant differences (LSD) at $P < 0.05$. Same letters within a column indicated there was no significant difference according to the Duncan test at $P < 0.05$

NPK in Barley grains

Table (9) showed average content of NPK in barley grain. Elements content in barley grain showed considerable variation based on zeolite doses and types, in addition to irrigation quantity of water. At Q2 irrigation water, the content of Nitrogen element in barley grain increased due to increase zeolite doses compared to control treatment, where the percentage of increase was 8.02%, 13.05% and 16.75% for Zd1, Zd2, and Zd3, respectively. As well, phosphorus content in grains increased by increasing zeolite doses. The percentages of increase were 12.28%, 20.03% and 26.89% for zeolite doses Zd1, Zd2, and Zd3, respectively, at Q2 irrigation water quantity. For potassium element it increased by percentage 3.52%, 4.76% and 9.84% for different zeolite treatment Zd1, Zd2, and Zd3, respectively, at Q2 irrigation water quantity. These results stated, that Zd3 was the best treatment. These findings may be due to sorption capability of zeolite -treated soil to nutrients that prevent its removal then release it gradually to plants (Perry & Keeling-Tucker, 2000 and Ahmed, 2010). Additionally, applying zeolite to soil enhances soil condition and fertility by influencing microbial activity and soil structure (Garau *et al.*, 2007). Ozbahce *et al.* (2015) mentioned that zeolite application to calcareous soil raised the amounts of N, K, Zn, Mn, and Cu in plant tissues. As well, Ahmed (2010) demonstrated that Clinoptilolit Zeolite showed the best N, P and K uptake in plant tissues because of less leaching of these nutrients and helps to retain nutrients in root zone by enhancing nutrient absorption.

Similarly, thermal activated zeolite doses influenced significantly on grain content of NPK. For nitrogen the percentage of increase was 14.30%, 23.49% and 26.18 % for AZd1, AZd2, and AZd3, respectively at Q2 irrigation water quantity. For phosphorus the percentage of increase was 23.75%, 35.21%, and 39.72% for AZd1, AZd2, and AZd3, respectively at Q2 irrigation water quantity. The percentage of increase in potassium content was higher in AZd3 (15.92) compared to other activated zeolite treatments, followed by AZd2 (12.67%) then AZd1 (5.12%) at the same irrigation water quantity. Thermal activation of zeolite improves its porosity so, its ability to retain more ions and water molecules increase (Kalita *et al.*, 2020). Thus, zeolite application to calcareous soil raised the amounts of N, K, Zn, Mn, and Cu in plant tissues (Ozbahce *et al.*, 2015). Interaction between zeolite doses x irrigation water quantities has significant effect on NPK grain content. Available nutrients increased by increasing the amount of irrigation water that might due to increase microbial activity in soil environment that encourage oxidation and biodegradation of organic fertilizers as mentioned by Gallardo-Lara & Nogales (1987) and Antoniadis & Alloway (2003).

The interfering effect of irrigation quantities, type of zeolite and concentration of its addition on the actual water consumption of barley (Table 10):

1- Effect of water quantities on actual water consumptive

The results showed that, by increasing the amount of added, the barley water consumption increased and vice. Applied water quantities significantly raised the actual water use. These findings align with those of Abdel-Ghany and Abd El-Aleem (2020) on *Pelargonium graveolens*, Abd-Elghany *et al.* (2017) on fenugreek, and El-Boraie *et al.* (2009) on peanut plants. The water consumption increased with treatment Q3 by a percentage 16.8% compared to treatment Q1.

2-Effect of Zeolite type on actual water consumptive

Through the statistical analysis of the results, it was found that activated zeolite had an effective role in the plant's tolerance to water shortages and reduced water consumption by 2.53% compared to natural zeolite.

3-Effect of Zeolite concentration on actual water consumptive

It was found that the amount of zeolite added had a significant effect on actual water consumption of barely plants, as there was a significant decrease in water consumption by 5.7% by increasing the amount of zeolite from zero to 300 kg/f.

4- The interaction effect between water quantities and Zeolite type on actual water consumptive

The results of the interaction between the amounts of water and the type of zeolite showed that treatment ZQ1 (irrigation amount 60% with the addition of natural zeolite) had the lowest water consumption by 3%compared to treatment AZ Q3 (irrigation amount 100% with the addition of modified zeolite) which recorded the highest water.

5- The interaction effect between water quantities and Zeolite concentration on actual water consumptive

By studying the interfering effect between the amounts of added zeolite and the amounts of irrigation water, adding 300kg/f had a significant effect on improving the soil's ability to retain water and helping the plant tolerate water shortages. Consequently, there was a decrease in the amount of water consumed with treatment d3Q1, which achieved the lowest water consumption by 19.5% compared to treatment (d0Q3).

6- The interaction effect between Zeolite type and Zeolite concentration on actual water consumptive

From the results obtained, it was found that concentration of the addition had a leading role over the type of zeolite, and the effect of concentration was more evident with the modified zeolite than natural case. The addition of 300 kg/f of the modified zeolite was 7.6% less water consumption than natural zeolite treatment with zero addition rate (AZd0).

7- The interfering effect of irrigation quantities, type of zeolite and concentration of its addition on the actual water consumption of barley

Through the results of the experiment and statistical analysis of the data, it was found that the interaction between the amounts of water and both type and concentration of zeolite has a clear significant effect on the actual water consumption of the barely plant. The irrigation treatment of 60% 0f irrigation needs with natural zeolite at a concentration of 300kg/fed had the lowest water consumption by 21.5% compared to the (AZd0Q3) treatment.

Table 10. The interfering effect of irrigation quantities, type of zeolite and concentration of its addition on the actual water consumption of barley

Zeolite type	Zeolite doses	Q1	Q2	Q3
			m^3/fed	
Z	d0	1892.5 hi	2012.9 e	2230.6 a
	d1	1826.6 k	1981.1 f	2157.5 b
	d2	1803.3 lm	1973.8 f	2156.2 b
	d3	1780.7 n	1942.7 g	2069.9 d
AZ	d0	1888.9 hi	1979.2 f	2157.1 b
	d1	1813.2 kl	1896.4 h	2097.4 c
	d2	1752.0 o	1871.4 ij	2065.7 d
	d3	1787.5 mn	1860.1 j	2057.3 d

variable	Q	Z	d	QxZ	Qxd	Zxd	QxZxd
$LSD_{0.05}$	8.7789	4.2350	7.6888	10.180	14.346	10.303	23.603

Q1, Q2, Q3: 60%, 80% and 100% of irrigation water, respectively - d0, d1, d2 and d3: 0, 100, 200 and 300 kg/fed zeolite or activated zeolite - Each value is an average of three replicates. Least significant differences (LSD) at $P < 0.05$. Same letters within a column indicated there was no significant difference according to the Duncan test at $P < 0.05$

The interfering effect of irrigation quantities, type of zeolite and doses of its addition on the barley yield and its component (Table 11):

1-Effect of water quantities on the barley yield and its component

The statistics result showed that the amount of water has the main role in the effect of the productivity of grain, straw and thus the total crop of barely. By increasing the amount of water the production increased. The best treatment was Q2 (80% of the irrigation needs), which has increased production rate by 86.5%,75.22% and 80.72% for each of the cereal, straw and the total crop respectively compared to Q1treatment (60% of irrigation needs).

2-Effect of Zeolite type on the barley yield and its component

The modified zeolite had a better effect on productivity compared to the treatment processed, causing increased in production by 5.45%, 12.52% and 98.9% for each of grain, straw and total crop in a row. This results agree with Mumpton (1999).

3-Effect of Zeolite type on the barley WUE

The results of the statistics indicated that the modified zeolite outperformed the processed zeolite in razing the efficiency of water consumption in rates of 8.84%, 15.75% and 12.21% for each the grains, straw and the total crop.

4-Effect of Zeolite concentration on the barley yield and its component

The zeolite concentration adding had a significant effect on production. It was the best treatment to add 200 kg/f, with the production of 65.04 %, 45.06% and 54.9 % for each of the grain, straw and the total crop in a row compared to the treatment of the control. In the same trend.

5- The interaction effect between water quantities and Zeolite type on the barley yield and its component

By studding the overlap between the amount of water and the type of zeolite, it was found that the treatment Q2 (80%) was the best transaction whether the natural or thermal laboratories zeolite El-Mahdy *et al.* (2022) found that the addition of zeolite improved all studied growth and production for soybean plant under water deficit. The best transaction (AZQ2) are followed by the treatment (ZQ2), achieving an increase in production 106.5 % and 101.1%, respectively compared with (ZQ1) treatment, which recorded the lowest productivity for the grain crop and the same trend was noticed with both straw and total crop.

6- The interaction effect between water quantities and Zeolite concentration on the barley yield and its component

By examining the interaction effect between water quantity and the concentration of adding, it was found that zeolite concentration affecting the plant's ability to with stand the water shortage and increase its production. The best transaction was d1Q2 followed by d2Q2, achieved in productivity by 137.1% and 102.3% compared to d0Q1, respectively.

7- The interaction effect between Zeolite type and Zeolite concentration on the barley yield and its component

The results of the statistical analysis indicated that the best productivity was obtained with AZ and concentration of 200 kg/f for each of grain and straw as well as the total crop. The ratio of 78.6%, 60.3% for grains, 75.6%, 28.5%% for straw, 77.12% and 43.19% for total crop compared to the treatment of the control for both AZ and Z, respectively.

8- The interfering effect of irrigation quantities, type of zeolite and concentration of its addition on the barley yield and its component

The statistics results for interference between transactions showed that the best productivity it gets from water treatment 80% of irrigation needs with AZ and the concentration of adding 200kg/fed, followed by transactions Zd2Q2 and AZd1Q2 investigators of 772.9kg/fed, 720.5 kg/fed and 638 kg/fed compared to the treatment Zd0Q1 which recorded the least productivity in the arrangement.

Table 11. The interfering effect of irrigation quantities, type of zeolite and doses of its addition on the barley yield and its component

Irrigation quantity	Zeolite type	Zeolite doses	Cereals	Straw (Kg/fed)	Total yield
Q1	Z	d0	330.0 o	361.2 m	691.2 p
		d1	489.5 k	451.0 kl	940.5 n
		d2	462.0 l	491.3 j	953.3 mn
		d3	379.5 n	497.2 j	876.7 o
	AZ	d0	430.8 m	507.8 ij	938.7 n
		d1	533.5 ij	531.7 hi	1065.2 jk
		d2	559.2 h	533.5 hi	1092.7 j
		d3	445.5 lm	440.4 l	885.9 o
Q2	Z	d0	623.3 g	552.6 h	1175.9 i
		d1	918.5 c	991.8 b	1910.3 c
		d2	1050.5 a	850.7 d	1901.2 c
		d3	748.0 ef	663.7 g	1411.7 h
	AZ	d0	628.8 g	803.0 e	1431.8gh
		d1	968.0 b	1068.8 a	2036.8 a
		d2	1072.9 a	907.5 c	1980.4 b
		d3	759.7 de	845.2 d	1604.9 e
Q3	Z	d0	469.3 kl	392.3 m	861.7 o
		d1	528.0 ij	487.7 jk	1015.7 kl
		d2	910.1 c	857.3 d	1767.3 d
		d3	777.3 d	711.3 f	1488.7fg
	AZ	d0	523.3 j	480.3 jk	1004.7lm
		d1	550.7 hi	473.0 jkl	1023.7 kl
		d2	907.5 c	852.5 d	1760.0 d
		d3	724.2 f	779.2 e	1503.3 f

Variable	Q	Z	d	QxZ	Qxd	Zxd	QxZxd
LSD $_{0.05}$(cereal)	12.28	9.26	8.23	16.68	17.2	13.63	27.86
LSD $_{0.05}$(straw)	16.76	12.03	11.9	22.28	24 20	18.82	39.35
LSD $_{0.05}$(total yield)	25.03	20.97	17.72	35.79	36.09	30.05	59.80

Q1, Q2, Q3: 60%, 80% and 100% of irrigation water, respectively - d0, d1, d2 and d3: 0, 100, 200 and 300 kg/fed zeolite or activated zeolite - Each value is an average of three replicates. Least significant differences (LSD) at $P < 0.05$. Same letters within a column indicated there was no significant difference according to the Duncan test at $P < 0.05$

The interfering effect of irrigation quantities, type of zeolite and concentration of its addition on the barley WUE (Table 12):

1-Effect of water quantities on the barley WUE

Through the results, it was found that there was an increase in the efficiency of water consumption with water shortages, and the amount of water Q2 was achieved the highest efficiency of water consumption in rates 37.31%, 45.05% and 41.03% for each grain, straw and total crop respectively compared to the treatment Q3. this result agree with Abd-Elghany *et al.* (2017), who found that water use efficiency by fenugreek plants increased as irrigation water depth decreased.

2-Effect of Zeolite type on the barley WUE

The results of the statistics indicated that the AZ outperformed the processed zeolite in razing the efficiency of water consumption in rates of 8.84%, 15.75% and 12.21% for each the grains, straw and the total crop.

3-Effect of Zeolite concentration on the barley WUE

The concentration of the zeolite had amoral effect on raising the efficiency of water consumption, as the concentration increased the efficiency increased. The best concentration 200kg/f, achieved an increase of 71%, 24.1% and 27.55% the conversion of the control, d1 and d3. This results are in line with Ippolito *et al.* (2011) concluded that applying zeolite at rate of 22 $Mgha^{-1}$ increased corn weight in comparison to control. Nevertheless, when the zeolite application rate raised to 90Mg ha^{-1}, there was a reduction in corn weight. This decrease was attributed to the higher sodium content.

4- The interaction effect between water quantities and Zeolite type on the barley WUE

The natural or modified zeolite had a clear role in raising the efficiency of water consumption with the decrease in the amount of water, these results in harmony with Bernardi *et al.* (2010) who found that addition of zeolite to the soil resulted in an enhancement of irrigation water use efficiency. This improvement was attributed to the increase in the soil's water hold in capacity and its improved availability to plants, especially the treatment Q2, which achieved the highest efficiency of water consumption with AZ, cause of an increase in the water consumption efficiency by 44.5% and 98.5% compared to the treatments ZQ3 and ZQ1, respectively, followed by the treatment ZQ2 causing an increase of 34.93% and 85.43% compared to the same previous transactions for grain and the same direction is observed with the straw and total crop.

5- The interaction effect between water quantities and Zeolite concentration on the barley WUE

The concentration of 200kg/f with amount of water Q2 (80%) was the highest efficiency of the consumer water, achieving 143.7% of the d0Q3 treatment for grain crop. while the d1Q2 transaction was the best in the case of the straw and total crop. This results are in the same direction with El-Mahdy *et al.* (2022) who found that the addition of zeolite improved all studied growth and production for soybean plant under water deficit treatments.

6- The interaction effect between Zeolite type and Zeolite concentration on the barley WUE

The concentration of the addition 200kg/f with AZ was the best in terms of the efficiency of water consumption, followed by the same focus with the Z for the grain crop, an increase of 90.84% and 74.3%

Table 12. The interfering effect of irrigation quantities, type of zeolite and concentration of its addition on the barley WUE

Irrigation quantity	Zeolite type	concentration	cereals	Straw (Kg/Fed)	Total yield
Q1	Z	d0	0.174 r	0.191 m	0.365 m
		d1	0.268 l	0.247 k	0.515hi
		d2	0.256 m	0.273 j	0.529 h
		d3	0.213 q	0.279 ij	0.492 jk
	AZ	d0	0.228 p	0.269 j	0.497 ij
		d1	0.294 k	0.293 hi	0.588 g
		d2	0.313 j	0.299 h	0.611 f
		d3	0.254 mn	0.251 k	0.506 hij
Q2	Z	d0	0.310 j	0.275 j	0.584 g
		d1	0.464 d	0.501 b	0.964 b
		d2	0.532 b	0.431 d	0.963 b
		d3	0.385 h	0.342 g	0.727 e
	AZ	d0	0.318 j	0.460 e	0.724 e
		d1	0.510 c	0.564 a	1.074 a
		d2	0.573 a	0.489 b	1.058 a
		d3	0.409 g	0.454 c	0.863 c
Q3	Z	d0	0.211 q	0.176 m	0.387 m
		d1	0.245 no	0.226 l	0.471 kl
		d2	0.422 f	0.398 e	0.820 d
		d3	0.376 h	0.344 g	0.719 e
	AZ	d0	0.243 0	0.223 l	0.466 l
		d1	0.263 lm	0.226 l	0.488 jk
		d2	0.439 e	0.413 e	0.852 c
		d3	0.352 i	0.378 f	0.731 e

variable	Q	Z	d	QxZ	Qxd	Zxd	QxZxd
LSD $_{0.05}$(cereal)	0.006	0.004	0.004	0.008	0.008	0.006	0.0109
LSD $_{0.05}$(straw)	0.0105	0.005	0.005	0.0128	0.0135	0.009	0.0159
LSD $_{0.05}$(total yield)	0.0151	0.0105	0.008	0.0198	0.0199	0.0150	0.0242

Q1: irrigatin quantity (60%), Q2: irrigation quantity (80%), Q3: irrigation quantity (100%), d0: control, d1: 100Kg/f, d2:200Kg/f, d3:300 Kg/f, Z: Natural Zeolite, AZ: Modified Zeolite. Each value is an average of three replicates compared to the treatment Zd0 (natural zeolite and zero concentration) that recorded the lowest value of the water consumption use efficiency. The same direction was observed with both the straw crop and the total crop.

7- The interfering effect of irrigation quantities, type of zeolite and concentration of its addition on the barley WUE

By studying the effect of the overlapping of transactions on the efficiency of water consumption of grains, the statistical analysis explained that the treatment (AZd2Q2) was the est transaction, followed by the treatment (Zd2Q2), achieving increased rate of 228.7% and 205.22%, respectively compared to the (Q1Zd0) treatment that recorded the lowest efficiency of water consumption. While the treatment of (AZd1Q2) is the best in the case of the straw crop followed by the (Zd1Q2) treatment with a 220.23% and 184.49% achievement compared to (Zd0Q3) treatment. In the case of the total crop, the best treatment was (AZd1 Q2) followed by the treatment (AZd2Q2), causing an increase of 194.11% and 189.8% compared to the (Zd0Q1) treatment.

CONCLUSION

There are numerous properties of natural zeolite, such as its high degree of crystallinity, specific surface area, and cation exchange capacity, which improved with thermal activation treatment. The results of this study suggested, that natural and thermal activated zeolite improved soil quality through increase CEC of soil environment, available NPK and increase soil DTPA extractable of Zn, Cu and Mn, and decreased soil EC. In addition, natural and thermal activated zeolite have a positive significant effect on the NPK content in barely grains. Thermal activation of zeolite was more effective in improving soil quality at all irrigation water quantities. To obtain the best soil quality and higher uptake of NPK by barley plant the best treatment recorded in this study was AZd3 (300kg/fed) at 80% (Q2) of irrigation water. Thus zeolites have positive effect not only in soil quality, but also in enhancing growth of parley plant and its water consumptive use efficiency.

RECOMMENDATION

From view of economic point, this study recommended to apply the transaction as AZd2 (200kg/fed) at 80% of irrigation water under the conditions of the study area, as it was the best transaction to provide soil quality, efficiency for water consumption, when using that water which was rationalized to grow new areas under the same treatment, it will raise production by 40.7%.

REFERENCES

Abd El-Azeiz E H., A. E. El-Sonbaty and M. A. El-Sherpiny. 2024. Enhancing the Quantitative and Qualitative Traits of Wheat Grown with Low Mineral Nitrogen Level through Zeolite, Sorbitol and Copper Egyptian Journal of Soil Science, 64(3):1053-1067.

Abdel-Ghany, G. G. and W. H. Abd El-Aleem. 2020.Effect of trickle irrigation and salicylic acid applications on quality and productivity of Pelargonium graveolens plant. Egypt. J. of Appl. Sci., 35 (5): 63-74.

Abd-Elghany, G. G., M.M. El-Shazly and H. A. E. A.Hashem. 2017. Water management for the fenugreek plant and its response to bio fertilization in north Sinai. Egypt. J. of Appl. Sci., 32 (12 B): 494 -515.

Abdul Aziz, H., A. F. M. Noor, Y. W.Keat, M.Y.D. Alazaiza and A. Abd Hamid. 2020.Heat Activated Zeolite for the Reduction of Ammoniacal Nitrogen, Colour, and COD in Landfll Leachate. International Journal of Environmental Research 14:463-478.https://doi.org/10.1007/s41742-020-00270-5

Ahmed, O. H. 2010.Selected growth variables, nutrient uptake, and yield of zea mays l. Cultivated with cocomposted wastes. Retrieved fromhttp://www.upm.edu.

Allen, E. R., L.R. Hossner, D.W. Ming and D.L. Henninger. 1993. Solubility and cation exchange in phosphate rock and saturated clinoptilolite mixtures. Soil Science Society. American Journal, 57:1368-1374.

Allen, R.G., L.S. Pereira, D. Raes and M. Smith. 1998. Crop evapotranspiration, guidelines for computing crop water requirements. Irrig. and Drain. Paper, No. 56, FAO, Rom, Italy.

Antoniadis, V. and B.J. Alloway. 2003. Evidence of heavy metal movement down the profile of a heavily-sludged soil. Commun. Soil Science of Plant Analysis, 34:1225–1231.

Badora, A. 2016. The Influence of Zeolites on Quality Indicators of Soil- Plant Connection and Food Safety. Licensee InTech. Ch. 11 http://dx.doi.org/10.5772/64590.

Badora, A., Z. Hubicki and T. Filipek. 2011. Action of two different zeolites on chosen experimental bottom properties and some chemical indicators of plants. Przem. Chem., 9:1779–1783. ID: YADDA bwmeta1.element.baz-tech-8502ba2a-75c3-4553-9eda-56d0094259d5.

Baghbani, A. A., S. A. M. Modarres-Sanavy and M.Poureisa. 2021. Improvement the Soil Physicochemical Properties and Fenugreek Growth Using Zeolite and Vermicompost under Water Deficit Conditions. Journal of Soil Science and Plant Nutrition 21:1213-1228 https://doi.org/10.1007/s42729-021-00434-y.

Bernardi, A. D. C., E. P. da Mota, S.D.C.H. D Souza, R. D. Cardoso and P. Oliveria. 2010. Ammonia volatilization, dry matter yield and nitrogen levels of Italian ryegrass fertilized with urea and zeolite . In World Congress of Soil Science., 19:22-25.

Bish, D. and J. Boak, Clinoptilolite-heulandite nomenclature. Rev. Mineral. Geochem. 2001, 45: 207–216.

Black, C.A. 1965.Methods of soil analysis. Part I, American Society of Agronomy. Madison, Wisconsin, USA. 1572.

Bybordi, A. 2016. Influence of zeolite, selenium and silicon upon some agronomic and physiologic characteristics of canola grown under salinity. Commun. Soil Science of Plant Analysis, 47 (7):832–850.

Cerjan-Stefanovic!, S., L. C!urkovic! and T. Filipan. 1996. Metal ion exchange by natural zeolites. Croat Chem Acta; 69(1):281–90.

Chen, Z.S., G.J. Lee, J.C. Liu. 2000.The effects of chemical remediation treatments on the extractability and speciation of cadmium and lead in contaminated soils. Chemosphere. 41: 235–242.

Comin, J.J., J. Barloy, G. Bourrie and F. Trolard. 1999. Differential effects of monomeric and polymeric aluminium on root growth and on the biomass production of root and shoot of corn in solution culture. European Journal of Agronomy, 11:115-122.

Cottenie, A., M. Verloo, L. Kiekens, G. Velgh and R.Camerlynck. 1982. Chemical Analysis of Plant and Soils.Lab. Anal. Agrochem. State Univ. Ghent, Belgium, 63.

Çulfaz, M. and M. YağızIon. 2004. Exchange properties of natural clinoptilolite: lead–sodium and cadmium–sodium equilibria. Separation and Purification Technology,37(2):93-105.

Dhank, W.C. and G.V. Johnson. 1990. Testing Soils for Available Nitrogen. In: 'Soil Testing and Plant Analysis', 3rd Ed., SSSA book series No. 3, R.L. Westerman (Ed.). Madison, WI: Soil Science Society. American Journal: 127-139.

Dogan A. U. 2003.Zeolite Mineralogy and Cappadocian Erionite. Indoor and Built Environment.12, 5. https://doi.org/10.1177/142032603036408

Earth Science Division of CAS. 1998. The way-out of problems of the water resources in China. Adv Earth Science, 13:113–117. Chinese.

El-Boraie, F.M., H.K. Abo-El-Ela and A.M. Gaber. 2009.Water requirements of peanut grown in sandy soil under drip irrigation and biofertilization. Aust. J. Basic & Appl. Sci., 3(1): 55-65.

El-Ghamry, A., D.A. Ghazi, M. A. Elsherpiny, M. A. Kassem, A. Kassem and A.A. Helmy. 2024.Enhancing onion growth and yield quality via soil amendments and foliar nutrition under deficit irrigation. Egyptian Journal of soil Science, 64(2):523-542.

El-Mahdy, S. M., M. A. El-Sherpiny and A. A. Helmy. 2022. Suppression of irrigation water deficit stress affecting soybean production. Journal of Global Agriculture and Ecology: 25-37.

El-Sherpiny, M. A., A. G.Baddour and M. M. El-Kafrawy. 2020). Effect of zeolite soil addition under different irrigation on maize yield (Zea mays L.) and some soil properties. Journal of Soil Sciences and Agricultural Engineering, 11(12):793-799.

FAO. 1970. Physical and chemical methods of soil and water analysis. Soils Bull. No. 10. Rom, Italy.

Gallardo, L. F. and R. Nogales. 1987. Effect of the application of town refuse compost on the soil-plant system: A review. Biological Wastes 19:35–62.

Garau, G., P. Castaldi, L. Santona, P. Deiana and P. Melis. 2007. Influence of red mud, zeolite and lime on heavy metal immobilization, culturable heterotophic microbial populations and enzyme activities in a contaminated soil. Geoderma, 142:47–57.

Giriappa, S. 1983. Water use efficiency in agriculture. Agricultural Development and Rural Transformation Unit. Institute for Social and Economic Change Bangalore. Oxford & IBH Publishing Co.

Ippolito, J. A., D. D.Tarkalson and G. A. Lehrsch. 2011. Zeolite soil application method affects inorganic nitrogen, moisture and corn growth. Soil science, 176(3): 136-142.

Israelson, O.W. and V.E. Hansen. 1962. Irrigation principles and practices, 3rd Ed., John Willey and Sons Inc., New York, USA

Jeevika, K., B. B. Saliha and M. Vijayakumar. 2015. Soil quality indicators based recommendation to maximize sugarcane productivity in Theni district of Tamil Nadu. Journal of Applied and Natural Science, 7: 215–218.

Kaduk, J.A., and J.Faber. 1995. Crystal structure of zeolite Y as a function of ion exchange. Rigaku Journal, 12(2):14-34.

Kalita, B., S. S. Bora and B. Gogoi. 2020. Zeolite: A Soil Conditioner. International Journal of Current Microbiological Applied Science, 9(01): 1184-1206. doi: https://doi.org/10.20546/ijcmas.2020.901.133.

Karami, S., H. Hadi, M. Tajbaksh and SAM. Modarres-Sanavy. 2020. Effect of zeolite on nitrogen use efficiency and physiological and biomass traits of amaranth (amaranthus hypochondriacus) under waterdeficit stress conditions. Journal of Soil Sciece Plant Nutrients 20:1427–1441. https://doi.org/10.1007/s42729-020-00223-z

Kavvadias, V., Z. Ioannou, E. Vavoulidou and C.h. Paschalidis. 2023.Short Term Effects of Chemical Fertilizer, Compost and Zeolite on Yield of Lettuce, Nutrient Composition and Soil Properties Agriculture, 13:1022.

Khairinal, l. and W. Trisunaryanti. 2000. Dealumination of natural Wonosari zeolite with acid treatment and hydrothermal process.In national seminar on chemistryVIII, proceeding, Yogyakarta.

Khalifa, THH, M. S. Elsaka, M.A. Shabana and H. M. Abo Elsoud. 2019. Effect of zeolite and mineral fertilizers on some soil properties and growth of Jew's mallow in clay and sandy soils . International Journal of plant and soil Science,3(12):1-12.

Kuldeyev, E., M. Seitzhanova, S. Tanirbergenova, K. Tazhu, E. Doszhanov, Z. Mansurov, S. Azat, R. Nurlybaev and R. Berndtsson. 2023. Modifying natural zeolites to improve heavy metal adsorption. Water, 15: 2215.

Kurniasari, L., M. Djaeni and A. Purbasari. 2011. Aktivasi zeolit alam sebagai adsorben pada alat pengering bersuhu rendah. Reaktor Chemical Engineering Journal 13:1178-1184.

Li, H., W. Shi Y., H. B. Shao and M.A. Shao. 2009.The remediation of the lead-polluted garden soil by natural zeolite. Journal of Hazardous Materials, 169:1106–1111.

Lija, M., O.H. Ahmed and S. Kasim. 2014. Maize (Zea mays L.) nutrient use efficiency as affected by formulated fertilizer with Clinoptilolite Zeolite. Emirates Journal of Food Agriculture. 26(3):284-292.

Lima, D.L.D., S.M. Santos, W.H. Scherer, R.J. Schneider, A.C. Duarte, EBH. Santos and V.I. Esteves. 2009. Effect of organic and inorganic amendments on soil organic matter properties. Geoderma. 150:38–45. https: //doi.org/10. 1016/j.geoderma. 2009 .01.009

Lindsay, W.L. and W.A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. SSSAJ 42:421–428.

Mansouri, N., N. Rikhtegari, H. A. Panahi, F. Atabi, B. Ehrouz and K.A. Shahraki. 2013. Porosity, characterization and structural properties of natural zeolite -clinoptilolite- as a sorbent. Environment Protection Engineering, 39

Micu, D., C. Proca, C. Ioana, C. Podaru and G.Burtica. 2005. Improvement possibilities of soil quality. Chem. Bull. “POLITEHNICA” Univ. (Timişoara). 50:1–2:108–111.

Molina, V.F. 2013. Soil colloids. Properties and ion binding. CRC Press, Surfactant 23 science series, vol. 156. Taylor & Francis Group, an informa business, Boca Raton London-New York, 513.

Mumpton, F.A. 1999. La Roca Magica: uses of natural zeolites in agriculture and industry. Proceedings of the National Academy of Sciences, USA. 96:3463–3470. doi:10.1073 /pnas.96.7.3463

Munir, N., A. Javaid, Z. Abideen, B. Duarte, H. Jarar, A. El-Keblawy, M.S. Sheteiwy. 2024. The potential of zeolite nanocomposites in removing microplastics, ammonia, and trace metals from wastewater and their role in phytoremediation. Environmental Science Pollutant Research, 31 (2): 1695–1718. https://doi.org/10.1007/s11356-023-31185-1.

Nasseem, M.G., M.A. Hussin, W.H. Mohmed and A.M. Saleh. 2011. Effects of Zeolite, Compost and Unisal on Growth and Elemental Composition of Barley (Hordeum sp.) Plants Irrigated With Saline Water. Alex. Sci. Exch. J.32.4.pp.400-408.

Navrotsky. A., I. Petrovic, Y. Hu, C.Y. Chen and M.E. Davis. 1995. Energetics of microporous materials. Journal of Noncrystalline Solids. 192–193:474–477. doi:10.1016/0022-3093(95)00392-4

Noori, M., M. Zendehdel and A. Ahmadi. 2006. Using natural zeolite for the improvement of soil salinity and crop yield. Toxicological & Environmental Chemistry, 88 (1):77-84.

Ozbahcea, A., A. F.Tarib, E. Gönülalc, N. Simseklic and H. Pademd. 2015. The effect of zeolite applications on yield components and nutrient uptake of common bean under water stress. Archives of Agronomy and Soil Science, 61(5) : 615–626. http://dx.doi.org/10.1080/03650340.2014.946021.

Page, A. L., R. H. Miller and D. R.Keeney. 1984. In “Methods of Soil Analysis”. Part 2: Chemical and Microbiological Properties. Second Edition. American Society Agronomy. Inc., Soil Science Society American Inc. Pub. Madison, Wisconsin, USA.

Peri!c, J., M. Trgo, Vukojevi!c and N. Medvidovi!c. 2004. Removal of zinc, copper and lead bynatural zeolite-a comparison of adsorption isotherms. Water Research 38 : 1893–1899

Perry, C.C. and T. Keeling-Tucker. 2000. Model studies of the precipitation of silica in the presence of aluminum; implications for biology and industry Journal of Inorganic Biochemistry. 78: 331–339. ISSN 0162-0134.

Pitcher, S.K., R. C. T. Slade and N. I. Ward. 2004. Heavy metal removal from motorway stormwater using zeolites. Science of the total environment. 161–166. PMID: 15504502.

Purbaningtias, T. E., B. Wiyantoko, P. Kurniawati, D. Prasetyoko and Suprapto .2017. The effect of aging temperature on natural zeolite modification . AIP Conf. Proc. 1911, 020013. https://doi.org/10.1063/1.5016006

Ramesh, K. and D. D.Reddy. 2011. Zeolites and Their Potential Uses in Agriculture - Chapter Four. .Advances in Agronomy. 113-219-241. https://doi.org/10.1016/B978-0-12-386473-4.00004-X

Ravali, C., K. J. Rao, T. Anjaiah and K. Suresh. 2021. Soil application of zeolite affects inorganic nitrogen, water soluble and exchangeable potassium. International Journal of Environment and Climate Change, 11(11):267-273.

Restiawaty, E., V.A. Gozali, TASE. Wibisono and Y.W. Budhi. 2024.Utilizing modified clinoptilolite for the adsorption of heavy metal ions in acid mine drainage. CSCEE 9, 100706.

Shokouhi, A., M. Parsinejad and H. Noory. 2015. Impact of zeolite and soil moisture on P uptake. In Proceedings of the 2nd Berlin-European Sustainable Phosphorus Conference (ESPC 2), Berlin, Germany,

Soltanpour, P.N. 1991. Determination of Nutrient Availability and Elemental Toxicity by AB-DTPA Soil Test and ICPS. In: ‘Advances in Soil Science’ Springer, New York, 165-190.

Sulaiman, K. O., M. Sajid, Kh. Alhooshani. 2020. Application of porous membrane bag enclosed alkaline treated Y-Zeolite for removal of heavy metal ions from water.Microchemical Journal.152 https://doi.org/10.1016/j.microc.2019.104289

Suradkar, R.K., P. P. Kadu, A. D. Kadlag, A.G. Durgude and U. S. Surve. 2023.Effect of zeolite application on physico-chemical properties of soil at grand growth stage and after harvest of preseasonal sugarcane grown on inceptisol The Pharma Innovation Journal; 12(8): 705-710

Szatanik-Kloc,A., J. Szerement, A. Adamczuk and G. Jozefaciuk. 2021. Effect of low zeolite doses on plants and soil physicochemical properties .Materials ,14(10):2617.

Taalab, A.S., G.W. Ageeb, H.S. Siam and S.A. Mahmoud. 2019. Some characteristics of calcareous soils. A review. Middle East Journal of Agricultural Research, 8:96-105.

Tallai, M., A. Olah Zsuposne, Z. Sandor and J. Katai. 2017. The effect of using zeolite on some characteristics of sandy soil and on the Amount of the test plant biomass. Ann. Ser. Agric. Silvic. Vet., 6: 115–120.

Torma, S., J. Vilcek, P. Adamisi, E. Huttmanova and O. Hronec. 2014. Influence of natural zeolite on nitrogen dynamics in soil. Turkish Journal of Agriculture and Forestry,38:739-744.

USGS. Mineral Commodity Summaries: Zeolites (Natural). 2016. Available online: http://minerals.usgs.gov/minerals/pubs/ commodity/zeolites/index.html (accessed on 31 December 2020).

Usman, A.R.A., Y. Kuzyakov, K.L. Orenz and K. Spahr. 2006. Remediation of a soil conta- minated with heavy metals by immobilizing compounds. Journal of Plant Nutrition and Soil Science, 169:205-212. DOI: 10.1002/jpln.200421685

Wahba, M.M., F. Labib and A. Zaghloul. 2019. Management of calcareous soils in arid region. International Journal of Environmental Pollution Environ Model 2:248–258.

Waldrip, H.M., R.W. Todd and N.A. Cole. 2014. Can surface applied zeolite reduced ammonia losses from feedyard manure? (In) Paper presented at ASA,CSA and SSSA International Annual Meetings, 2-5 November 2014, Long Beach,CA.

Walkley, A. and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37:29–38. doi:10.1097/00010694-193401000-00003

Wasielewski, S., E. Rott and R. Minke. 2018. Steinmetz, H. Evaluation of Different Clinoptilolite Zeolites as Adsorbent for Ammonium Removal from Highly Concentrated Synthetic Wastewater. Water, 10, 584.

Wibowo, E., M. Rokhmat and M. Abdullah. 2016. Why does thermal shock produce smaller particles of zeolite? Powder Technol. 301:911–919

Williams, H., T. Colombi and T. Keller .2020. The influence of soil management on soil health: An on-farm study in southern Sweden. Geoderma.; 360:114010

Wu, Q., D. Xia, G. Chen, T. Sun and Y. Song. 2019. Effects of zeolite on drought resistance and water – nitrogen use efficiency in paddy rice. Journal of Irrigation and Drainage Engineering, 145(11):04019024.

Zheng, J., T. Chen, D. Chi, G. Xia, Q. Wu, G. Liu, W. Chen, W. Meng, Y. Chen, K.H.M. Siddique. 2019. Influence of Zeolite and Phosphorus Applications on Water Use, P Uptake and Yield in Rice under Different Irrigation Managements. Agronomy, 9;537.

الملخص العربي

رفع كفاءة الإدارة المائية وجودة التربة باستخدام الزيوليت المعدل

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إن التغيرات المناخية ونقص المياه وتدهور جودة التربة، إلى جانب ارتفاع الطلب على الغذاء، تتطلب نظام زراعة أكثر فعالية. وقد تناولت هذه الدراسة دور الزيوليت الطبيعي (Z) والزيوليت المعدل (المنشط حرارياً) (AZ) (٣٠٠ – ٤٠٠ درجة مئوية لمدة ٣ ساعات) في تحسين جودة التربة ونمو نبات الشعير بأربع جرعات: 0 (d0)، و١٠٠ (d1)، و٢٠٠ (d2)، و٣٠٠ (d3) كجم/ فدان بثلاث كميات من مياه الري Q1 (٦٠٪)، وQ2 (٨٠٪)، وQ3 (١٠٠٪)، من خلال التجربة الحقلية. وقد أشارت النتائج إلى أن (Z) و(AZ) زادا من السعة التبادلية الكاتيونية (CEC) لبيئة التربة، والمتاح من النيتروجين والفوسفور والبوتاسيوم (N-P-K)، وزيادة المستخلص بواسطة (DTPA) من الزنك (Zn) والنحاس (Cu) والمنجنيز (Mn)، وخفضا ملوحة التربة (EC) خاصة عند الزيوليت المعدل (٣٠٠ كجم/ فدان) عند ٨٠٪ من مياه الري (AZd3Q2)، تليها (AZd2Q2)، ثم (AZd1Q2).

بالإضافة إلى ذلك: عزز الزيوليت المعدل امتصاص (N-P-K) بواسطة حبوب الشعير؛ حيث كانت أفضل نسب الزيادة الملحوظة: ٢٦,١٨٪، و ٣٩,٧٢٪، و ١٥,٩٢٪، على التوالي لمعاملة (AZd3Q2). ومن ناحية أخرى كانت معاملة الزيوليت المعدل (٢٠٠ كجم/ فدان) عند ٨٠٪ من مياه الري (AZd2Q2) هي أفضل معاملة لاستهلاك المياه؛ حيث وفرت ٥٣٩,١ مترًا مكعبًا من مياه الري؛ مما قد يؤدي إلى زيادة الإنتاج بنسبة ٤٠,٧٪، وبالتالي اقترحت الدراسة اقتصاديًا أن (AZd2Q2) هو أفضل معاملة.

الكلمات المفتاحية: الزيوليت المعدل – جودة التربة – إدارة المياه.