Original Research Article

Effect of zeolite and mineral fertilizers on some soil properties and growth of Jew's mallow in clayey and sandy soils

ABSTRACT

Aims: to evaluate the effect of zeolite and mineral fertilizers on some soil properties, availability of soil nutrients and yield of Jew's mallow (*Corchorus olitorius*) in clayey and sandy soils.
Study design: The experimental designed as split plot design with three replicates, the main plots were devoted to zeolite at the rates of 0, 4.76 and 9.52 Mg ha^{-1} and the sub plots were occupied by mineral fertilizers at the rates of 50% and 100% from the recommended NPK doses.
Place and Duration of Study: During spring and summer seasons of 2018, the field experiments were conducted in Sakha Agricultural Research Station Farm (clayey soil) and private farm at Baltium district (sandy soil).
Methodology: Jew's mallow grains (*Alexandria variety*). Soil samples were collected at (0-30 cm depth) in the initial of experiment and after harvesting with the aid of soil auger at random from different parts of the experimental sites to determine the physicochemical and soil moisture characteristics of the soil. Growth characteristics (plant height and fresh mass weight) were studied.
Results: The results showed that ECe, SAR and bulk density values were decreased, while CEC, total porosity, field capacity, permanent wilting point and available water values increased due to application of 9.52 Mg zeolites ha^{-1} when compared to untreated soil. The maximum stem height and total fresh yield of Jew's mallow were recorded with the application of 9.52 Mg zeolite ha^{-1}+100% NPK.
Conclusion: It could be concluded that the use of zeolite in clayey and sandy soils improved the soil properties, improved the availability of soil nutrients and consequently decreased the environmental pollution. Also, the obtained results are promising for enhancing the horizontal and/or vertical expansion of agriculture in such problematic soils.

Keywords: Zeolite, Mineral fertilization, Jew's mallow, Soil properties, Soil nutrients, Clayey soil, Sandy soil.

1. INTRODUCTION

Corchorus olitorius, is known as "Jew's mallow", "molokhia","tossa jute", "bush okra", "krinkrin" or "West African sorrel", among many other local names [1]. It is an important green leafy vegetable in Egypt. Although the productivity of Okra in India is higher (11.6 t ha^{-1}) than world average productivity (7.35 t ha^{-1}) but lower than that of Egypt (15.70 t ha^{-1}) [2]. *Corchorus olitorius* is a vegetable eaten in both dry and semi-arid regions and in the humid areas of Africa. The nutritional constituents of *Corchorus olitorius* include calcium, protein, oil and carbohydrates; iron, magnesium and phosphorus.

Soil is one of the most important environmental factors and is considered the main source of the essential plant nutrients, water reserves and a medium for plant growth [3]. Maintaining or improving soil quality is crucial for agricultural productivity and environmental safety, which are to be preserved for future generations [4, 5].

The excess and unbalanced of fertilizers causing environmental pollution which have been globally expressed. The low fertility is one of the constraints and could impede the effort to achieve global of food security and prevent environmental pollution. For that, more studies should be done on efficient methods to reduce nutrient applications at the same time increasing crop yield and production, reducing nutrient losses and improve nutrient use efficiency [6].

Zeolites are crystalline, hydrated aluminosilicates of alkaline earth cations with three dimensional networks of AlO_4^{-5} and SiO_4^{-4} tetrahedral, linked by sharing of oxygen atoms. Zeolites can absorb up to 55% water, which can be used by the plants for their metabolic activities [7]. Zeolite improves the efficiency of water use by increasing the water holding capacity of soil and its availability to plant [8]. Application of Zeolite improves soil fertility, physical and chemical properties and it is very useful in draught conditions, because it absorbs a high quantity of water in its pores. Also, Zeolite can retain soil nutrients in the root zone to be used by plants when required [9]. The utilization of Zeolites in agriculture as a carrier of plant nutritional elements its feasible simply because of the high sorption capacity of this rock, special cation exchange properties and sorption [10]. When nutrients are introduced into the soil in this way, their consumption is reduced, so there is no need for redundant delivery of raw materials and consequently fewer nutrients.(mostly nitrogen), which causes pollution of water source are leached into ground and surface water [11]. The changes in soil physical properties carried out by addition of Zeolites lead to increase in the soil water retention capacity and also decrease its percolation [12]. Zeolite improves physical properties such as water conductivity, ventilation and soil moisture, as well as mitigating soil erosion caused by surface runoff, reducing soil loss, and improving degraded pastures [13]. Zeolite amendment helps in increasing the CEC of soil [14, 15]; decreasing of SAR and soil bulk density, while CEC, total porosity and available nutrient contents (N, P, K, Fe, Mn and Zn) were increased [16]. Also, [17] noted that the use of zeolite with sandy soils in arid and semi-arid areas resulted in improved cationic capacity and soil ability to retain moisture and reduce evaporation with a significant increase in retention of nutrients, especially K, Al and Ca. [18] showed that the addition of zeolite to the sandy soil has improved its physical properties by increasing total porosity, ready water and soil absorption of water. [19] showed that the use of zeolite can increase soil pH, total N content, available P_2O_5 and CEC.

Chemical fertilizers are inorganic fertilizers which are most important to increase growth and yield of *Corchorus olitorius*. They are formulated in appropriate concentrations and combinations which supply N.P.K for various crops. N promotes leaf growth and forms proteins and chlorophyll, P contributes to root, flower and fruit development, while K contributes to stem and root growth and the synthesis of proteins [20]. [21] found that the soil application of NPK significantly increased the plant height, number of leaves, fresh shoots, dry matter of *Corchorus olitorius* above the control (no fertilizer). The growth and yield of nutritional value of Jew’s mallow plants attributes to increase of NPK rates from 30 to 90 units/fed [22].

1.1 Objective of the Study

The objective of this study it was to evaluate the effect of zeolite and mineral fertilizers on some soil properties, availability of soil nutrients and yield of Jew’s mallow (*Corchorus olitorius*) in clayey and sandy soils.

2. MATERIALS AND METHODS

2.1. Experimental Location and Design

Two field experiments were conducted in Sakha Agricultural Research Station Farm (clayey soil) (Latitude 31°05'21.10"N and Longitude 30°56'01.11"N), and in private farm at Baltium district (sandy soil) (Latitude 31°35'10.11"N and Longitude 31° 5'11.89"E), North Delta, Kafr El-Sheikh Goverorate, Egypt, during spring and summer seasons of (2018). The experiment aimed to evaluate the effect of zeolite and mineral fertilizers on some soil properties, availability of soil nutrients and yield of Jew’s mallow (*Corchorus olitorius*) in clayey and sandy soils. The experimental site was prepared and divided into plots (2 m x 2 m) and designed as split plot design with three replicates, the main plots were devoted to zeolite at the rates of 0, 4.76 and 9.52 Mg ha^{-1} and the sub plots were occupied by mineral fertilizers at the rates of 50% and 100% from the recommended NPK doses.

2.2. Cultural practices

For spring, Jew's mallow grains (*Alexandria variety*) were sown on March, 5 and 7, 2018 and harvested on April, 20 and 24, 2018, while for summer were sown on April, 23 and 30, 2018 and harvested on June, 15 and 28, 2018 for clayey and sandy soil, respectively. The Jew's mallow was sown at the rate of 5 kg seeds fed^{-1}. NPK fertilization rates were split into three doses: the first (30%) at the first irrigation, further applications were distributed in the following irrigation over two times as 30% and 40%. The recommended doses of NPK fertilizers in the clayey soil were 238 kg ammonium sulphate ha^{-1} (20.6% N), 59.5 kg potassium sulphate ha^{-1} (48% K_2O) and 119 kg superphosphate (15.5% P_2O_5) ha^{-1}, while in the sandy soil, the recommended doses were 404.6 kg ammonium sulphate ha^{-1}, 95.2 kg potassium sulphate ha^{-1} and 238 kg superphosphate ha^{-1}. Turkish zeolite (soft) was thoroughly mixed with the surface soil layer (0-30 cm) before cultivation, the chemical composition of Zeolite presented in Table (1).Other agricultural practices were performed according to the Ministry of Agriculture recommendations in North Nile Delta.

Table (1). Chemical composition of zeolite.

SiO_2	Al_2O_3	CaO	K_2O	Na_2O	FeO	P_2O_5	pH	EC (dS m^{-1})	CEC (cmol kg^{-1})
(%)									
65.14	11	8.8	4.6	1.48	8.31	0.67	7.01	2.3	153

2.3. Soil sampling and analysis methods

Soil samples were collected at (0-30 cm depth) with the aid of soil auger at random from different parts of the experimental sites to determine the physicochemical properties of the soil. Soil properties were analyzed at the Laboratory of Soils Improvement & Land Conservation Department in Sakha Agric. Res. Station. Disturbed and undisturbed soil samples were taken in the initial of experiment and after harvesting. Soil reaction (pH) was measured in 1:2.5 soil extract according to [23]. Electrical conductivity (EC_e) was measured by electrical conductivity meter (model Jenway, 4320) as dS m^{-1} at 25 ^oC. Soluble Na^+, Ca^{++}, Mg^{++}, $CO_3^{=}$, HCO_3^-, Cl^- [24] and $SO_4^{=}$ were calculated by the difference between the sum of soluble cations and anions in soil paste extract. Sodium adsorption ratio (SAR) was calculated by using the soluble Na^+, Ca^{++} and Mg^{++} (meq L^{-1}) according to [25]**:**

$$SAR= Na \sqrt{(Ca^{2+} + Mg^{2+})/2}$$

Available N was extracted by 1.0 Mole K_2SO_4 and determined by MgO and devarda alloy using Kjeldahl method, Available K was extracted by ammonium acetate (1.0 N at pH 7) and determined by a flame photometer [26]. Available P was determined using sodium bicarbonate method according to [27]. Mechanical analysis (sand, silt and clay) were determined according to the international pipette method [28]. Soil bulk density of the soil was determined in undisturbed samples using clod method [29]. Total soil porosity was estimated from the bulk density and particle density of the soil [30] using the equation:

$$\text{Total Porosity} = (1- \rho b / \rho s) \times 100$$

Where: ρb is the bulk density and ρs is the particle density of soil solids (2.65 g cm^{-3}).

Pressure membrane was used to determine filed capacity (FC) of sandy and clayey soils under pressures of 0.1 and 0.33 bar, respectively, while welting point (WP) in both soils was estimated under pressure of 15 bars according to [31]. Available water (AW) in both soils was estimated as the difference between the moisture contents at FC and WP.

Data of physical, chemical and moisture characteristics of the tested soils are presented in Tables (2 and 3).

Table (2): Some chemical characteristics of the tested soils

Location	pH	EC_e (dS m^{-1})	Soluble cations (meq L^{-1})				Soluble anions (meq L^{-1})			SAR	CEC (cmol kg^{-1})
			Na^+	K^+	Ca^{++}	Mg^{++}	HCO_3^{--}	Cl^-	$SO_4^{=}$		
Sakha	8.02	3.64	20.02	0.4	10.2	5.8	4.5	18.2	13.72	7.08	39.44
Balteem	7.54	2.35	12.93	0.1	4.0	2.0	1.5	11.8	5.73	7.46	9.22

Table (3): Some physical and soil moisture characteristics of the tested soils:

Location	Particle size distribution (%)			Texture	BD (g cm^{-3})	Total Porosity (%)	Soil moisture characteristics (%)		
	Clay	Silt	Sand				Field capacity	permanent wilting point	Available water
Sakha	52.60	31.09	16.31	clayey	1.22	53.96	41.32	17.97	23.35
Balteem	6.12	7.61	86.27	sandy	1.67	37.0	6.31	2.21	4.10

2.4. Growth characteristics

The plant height and fresh mass weight Jew's mallow were measured. For the plant height, five plants from each plot were randomly sampled after six weeks to measure the length of the main shoot, and the fresh mass weight was determined.

2.6. Statistical analysis

The obtained results were subjected to statistical analyses according to the procedure outlined by [32], and significant differences were weighted by LSD test at 0.05 level of probability.

3. RESULTS AND DISCUSSIONS

3.1. Some chemical properties of soil as affected by different treatments

3.1.1. Electrical conductivity (EC_e)

Results in (Fig. 1 and 2) indicated that EC_e value of both soils slightly increased due to application of different treatments. The values of EC_e were slightly affected and showed 2.8 or 6.5% increases due to application of 0, 4.76 and 9.52 Mg zeolite ha^{-1} of clay soil, respectively, while in sandy soil the increases in ECe value were 3.2 or 4.4% with both zeolite rates, respectively comparing to the untreated soil. Also, ECe value in plots fertilized by full NPK requirements was slightly higher than that with 50% NPK by 1.3% for clay soil and by 1% in sandy soil. The interaction between both NPK and zeolite slightly affected soil salinity. However, the highest ECe values in clay soil (3.98 dS m^{-1}) and sandy soil (2.49 dS m^{-1}) were recorded as a result of the interaction of 9.52 Mg zeolite ha^{-1} with 100% NPK, while the lowest ECe values in both soils (3.69 and 2.36 dS m^{-1}, respectively) were achieved with 50% NPK without zeolite.

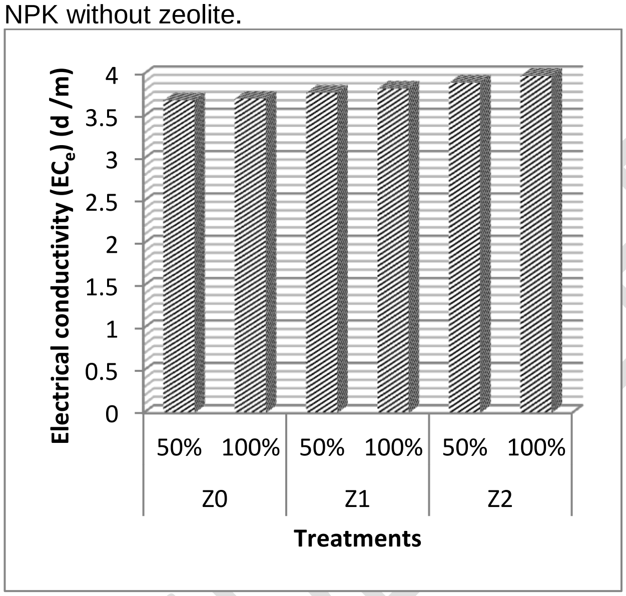

Fig (1) Effect of zeolite and NPK fertilization on ECe in clayey soil.

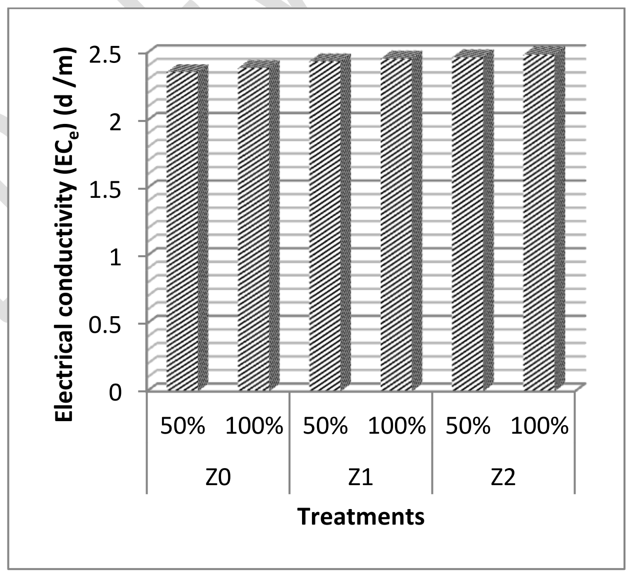

Fig (2) Effect of zeolite and NPK fertilization on ECe in sandy soil.

3.1.2. Sodium adsorption ratio (SAR)

The application of zeolite and NPK fertilization decreased SAR value after harvesting of Jew's mallow in both soils (Fig. 3 and 4). Regarding to the effect of zeolite, the highest decreases in SAR values in clay soil (27.8%) or in sandy soil (23.1%) were achieved as a result of application 9.52 Mg zeolite ha^{-1} when compared to that in untreated soil. In case of NPK levels, the addition of 100% decreased SAR values in clay soil by 8% and 1.6% in sandy soil comparing to that in plots fertilize by 50% NPK. Therefore, the lowest SAR values in clayey and sandy soils (4.70 and 5.24, respectively) were achieved by 9.52 Mg zeolite ha^{-1} combined with 100 % NPK, while the highest values in both soils (6.63 and 6.90, respectively) were obtained from the plots received 50% NPK without zeolite. Thus, an application of zeolite may increase Ca^{++} concentrations in the upper soil layer due to its high content from Ca^{++}, consequently decreased its SAR value. These results may be attributed the high content of zeolite from Ca^{++}. This trend is corresponding with results listed in Table (4) which showed that the concentrations of Ca^{++} and $SO_4^{=}$ clearly increased, while Na^{+} and Cl^{-} concentrations were decreased with zeolite application, especially with 9.52 Mg zeolite ha^{-1}. This is in accordance with [16-33] they observed that sodium and chloride content were decreased with increasing rate of zeolite.

Table (4) Relative change (± %) on some cations and anions with zeolite and NPK

Treatments		Clayey soil				Sandy soil			
Zeolite (Z)	NPK Ferti. (F)	Na^+	Ca^{++}	Cl^-	$SO_4^=$	Na^+	Ca^{++}	Cl^-	$SO_4^=$
Z_0	50 %	10.45	-7.84	10.70	-6.17	4.59	-10.00	4.79	-27.15
	100 %	10.70	-10.78	11.67	-11.79	8.04	-27.50	13.97	-34.28
Z_1	50 %	-6.22	33.33	-6.22	14.20	-10.64	40.00	-5.73	13.92
	100 %	-17.35	73.53	-17.35	33.92	-11.47	43.75	-6.60	17.88
Z_2	50 %	-20.13	88.24	-20.13	39.70	-16.14	60.00	-11.53	23.03
	100 %	-26.55	89.22	-26.55	42.32	-19.56	65.00	-15.14	37.25

Z_0: without Zeolite addition; Z_1: 4.76 Mg zeolite ha^{-1} ; Z_2: 9.52 Mg zeolite ha^{-1}.

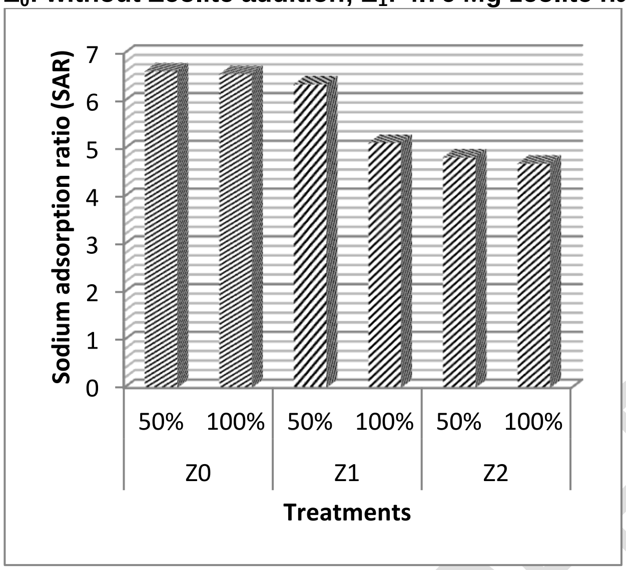

Fig (3) Effect of zeolite and NPK fertilization on SARe in clayey soil.

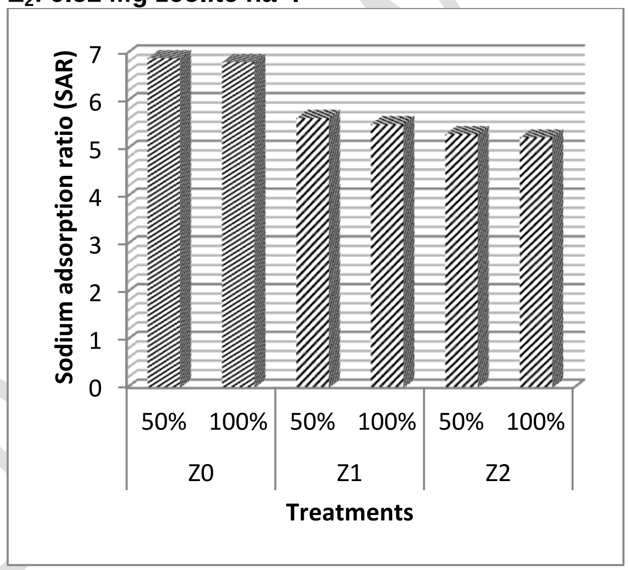

Fig (4) Effect of zeolite and NPK fertilization on SARe in sandy soil.

3.1.3. Cation Exchange Capacity (CEC)

Data showed pronounced increases in CEC values with addition zeolite (Figs. 5 and 6). The highest increases in CEC values for clay and sandy soils (7.8 and 28.7%, respectively) were recorded with 9.52 Mg zeolite ha^{-1}, over that in the untreated plots. On the other hand, the plots received full NPK doses have negligible changes in CEC comparing to that received 50% NPK. So, the highest CEC values in clayey and sandy soils (42.58 and11.92 cmol kg^{-1}, respectively) were achieved with application of 9.52 Mg zeolite ha^{-1} and 100% NPK, while the lowest values (39.45 and 9.23 cmol kg^{-1}, respectively) were recorded with 50% NPK without zeolite. These increases could be attributed to the high CEC values of zeolite is 2-3 times greater than that in mineral soils (153 cmol kg^{-1}). This is in accordance with [14,15,16,19].

3.1.4. Available Nutrient Content

The data in Table (5) proved that the available NPK contents in the clay and sandy soils seem to be in well levels and strongly increased as a result of zeolite and NPK applications. The results in (Fig. 1) revealed that the available N contents in both soils were clearly increased with application of zeolite and NPK fertilizations comparing to that before experiment (18.3 mg kg^{-1}). The highest nitrogen contents for clay and sandy soils (31.21 and 6.94 mg kg^{-1} with increases of 70.5 and 8.5% respectively) were obtained with application of 9.52 Mg zeolite ha^{-1} + 100% NPK followed by 4.76 Mg zeolite ha^{-1} + 100% NPK (28.52 and 6.86 18.3 mg kg^{-1} with 55.7 and 7.0% increases, respectively). The lowest available N contents for both soils were recorded without zeolite with 50% NPK (18.81 and 6.51 18.3 mg kg^{-1}, respectively), or with 100% NPK (20.46 and 6.60 18.3 mg kg^{-1}, respectively). The results showed that P and K contents were strongly increased with 9.52 Mg zeolite ha^{-1} + 100% NPK since it recorded the highest contents of them for clay soil (9.19 and 331.4 mg kg^{-1}, respectively) and sandy soil (3.05 and 40.7 18.3 mg kg^{-1}, respectively). The lowest P and K contents were obtained with 50% fertilization without zeolite in clay soil (6.63 and 239.5 18.3 mg kg^{-1}, respectively) and in sandy soil (2.46 and 35.5 18.3 mg kg^{-1}, respectively). These results may be related to that zeolites have ability to absorb gases and used as soil amendment to improve its performance as well as to provide a high proportion of mineral fertilizer required for plants [34]. Also, zeolites improve nutrient use efficiency through increasing P availability from its rocks, reducing leaching of K+ to be slow-release fertilizer [35]. It's also influenced positively the main nutrient content (N, P, K and Ca) in plants [36]. In addition, incorporation of zeolite into soil improves N assimilation, increases soil absorption, reduces N nitrification and reduces fertilizer wash off from soils [37] and the use of zeolite can increase total N content and available P_2O_5 [19].

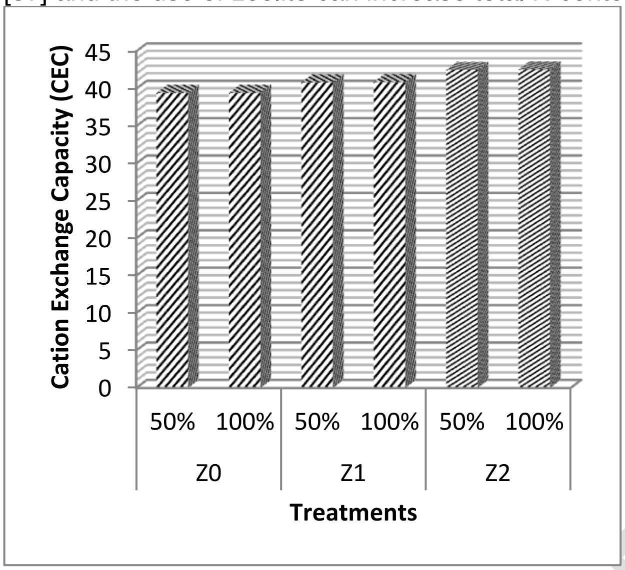

Fig (5) Effect of zeolite and NPK fertilization on CEC in clayey soil.

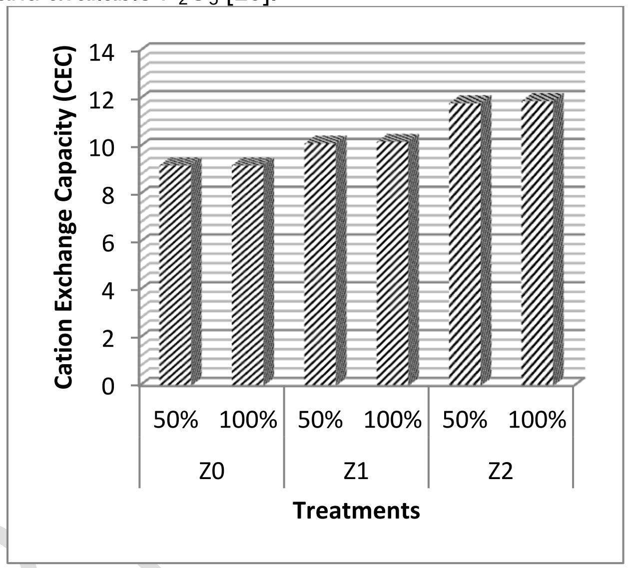

Fig (6) Effect of zeolite and NPK fertilization on CEC in sandy soil.

Table (5). Available NPK in surface layer of soil as affected by zeolite and NPK fertilization after harvesting

Treatments		Clayey soil			Sandy soil		
Zeolite (Z)	NPK Ferti. (F)	N	P	K	N	P	K
		(mg kg^{-1})			(mg kg^{-1})		
Z_0	50 %	18.81	6.633	239.5	6.51	2.46	35.5
	100 %	20.46	6.753	243.7	6.60	2.55	36.55
Z_1	50 %	22.73	7.247	252	6.68	2.7	37.4
	100 %	28.52	8.343	319.1	6.86	2.95	39.96
Z_2	50 %	24.39	7.727	285.5	6.77	2.833	39.65
	100 %	31.21	9.187	331.4	6.94	3.05	40.69
(Z) F-test & LSD		** 0.85	** 0.09	** 8.77	** 0.006	** 0.14	** 0.18
(F) F-test & LSD		* 1.19	ns	** 4.88	** 0.003	ns	* 0.63
(Z*F) F-test		ns	ns	*	**	ns	**

Z_0: without Zeolite addition; Z_1: 4.76 Mg zeolite ha^{-1} ; Z_2: 9.52 Mg zeolite ha^{-1}.

3.2. Some physical and soil moisture characteristics

3.2.1. Soil Bulk Density (BD)

In general, addition of 4.76 and 9.52 Mg zeolite ha^{-1} to clay and sandy soils decreased their BD as shown in Fig. 7 and 8 BD was slightly decreased from 1.22 to 1.19 g cm^{-3} in clay soil and from 1.66 to 1.60 g cm^{-3} in sandy soil due to application of 9.52 Mg zeolite ha^{-1}, while it was not affected by NPK fertilization levels. Decline of BD may be attributed to that zeolite improve the physical properties of soil in particular total porosity. This is in accordance with [16].

3.2.2. Total Porosity (T.P.)

The results as shown in Fig. 9 and 10 showed that total porosity was increased with zeolite application. The addition of 4.76 or 9.52 Mg zeolite ha^{-1} increased T.P. from 53.96 % to 54.72 or 55.09%, respectively in clay soil and from 37.36% to 40 or 41.51%, respectively % in sandy soil. There is no effect of NPK fertilization on total porosity. The results of porosity may be due to the high porosity of zeolite which led to improve of soil structure and decrease the soil density in both soils. These results are in agreement with [16, 18].

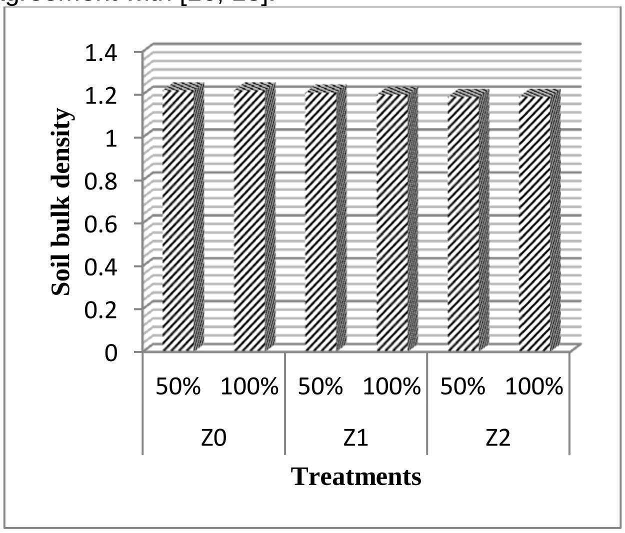

Fig (7) Effect of zeolite and NPK fertilization on soil bulk density in clayey soil.

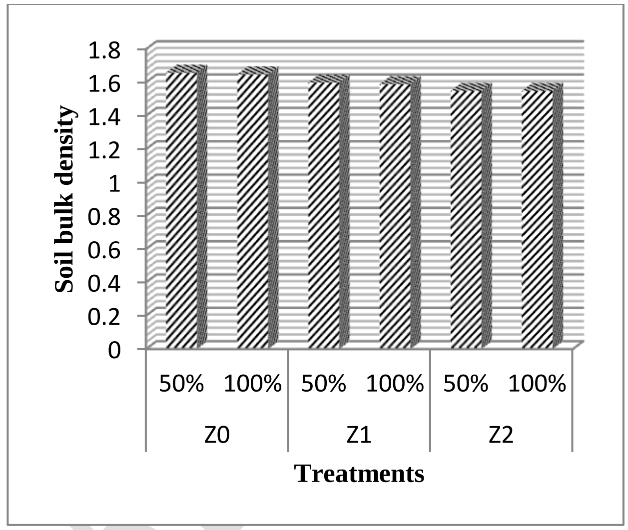

Fig (8) Effect of zeolite and NPK fertilization on soil bulk density in sandy soil.

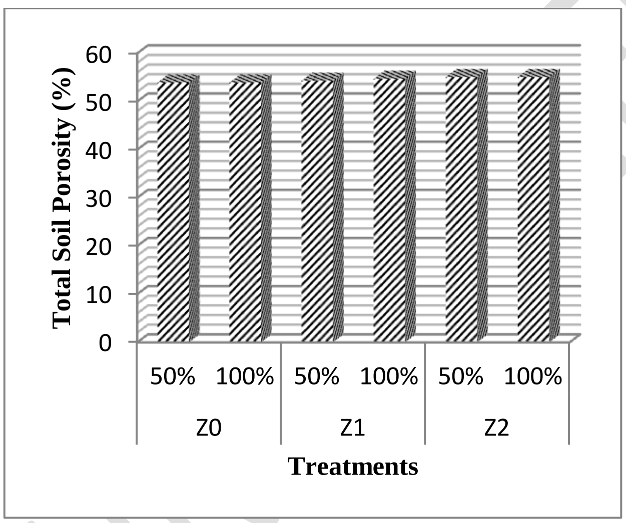

Fig (9) Effect of zeolite and NPK fertilization on total porosity in clayey soil.

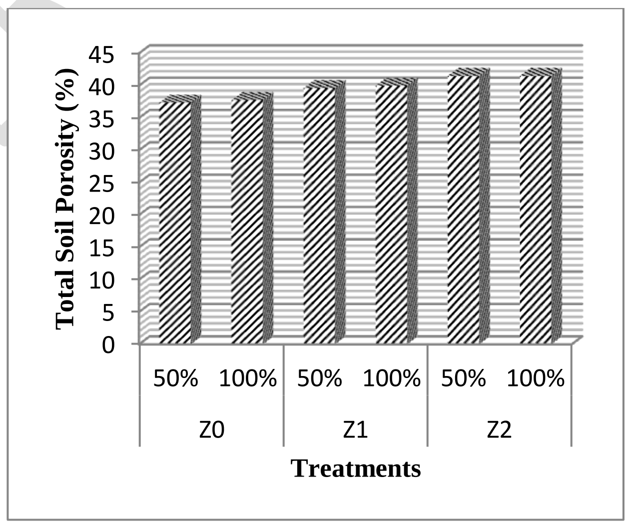

Fig (10) Effect of zeolite and NPK fertilization on total porosity in sandy soil.

3.2.3. Soil Moisture Characteristics (%)

Regarding to the effect of the studied treatments on the field capacity (FC), permanent wilting point (WP) and available water (AW), data in Fig. 11 and 12 cleared that the addition of zeolite especially with 9.52 Mg zeolite ha^{-1} increased these parameters. The highest values of FC, WP and AW in clay soil (43.9, 19.09 and 24.81%, respectively) and in sandy soil (8.28, 2.91 and 5.37%, respectively) were recorded with addition of 9.52 Mg zeolite ha^{-1}. The NPK fertilization was not affected these parameters. This behavior may be due to that zeolite absorbs a high quantity of water in its pores. Also, silica, aluminosilicates, zeolite is scaffold structure and water molecules occupation in its cavities and removable in its structure so that ion exchange reactions and dehydration do as reversible. So, the use of zeolite is one way to prevent soil moisture losses. This is in accordance with [7, 8, 12, 13, 17 and 18].

Also, the obtained results are agreed in somewhat with [38] who concluded that zeolite application lead to increase FC.

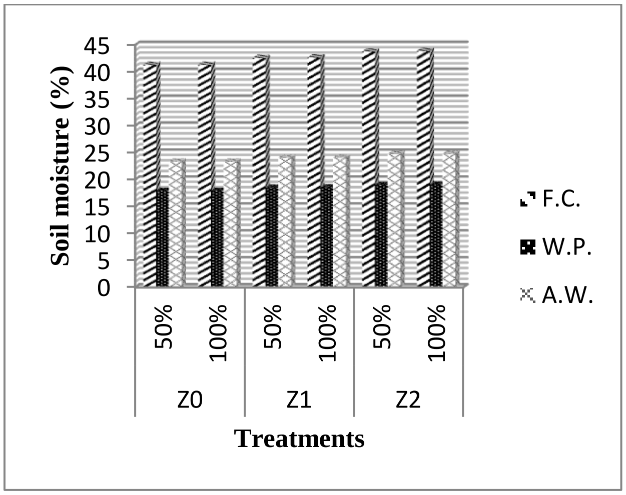

Fig (11) Effect of zeolite and NPK fertilization on soil moisture characteristics in clayey soil

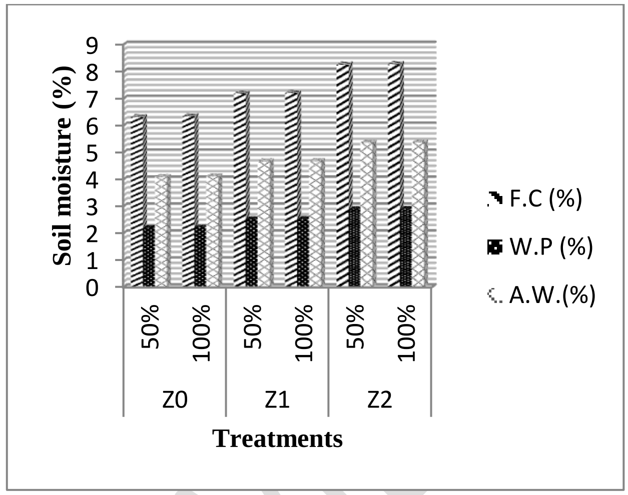

Fig (12) Effect of zeolite and NPK fertilization on soil moisture characteristics in sandy soil

3.3. Yield and its components

3.3.1. Stem height (cm)

It is clear from the data listed in Table (6) that the zeolite mixed with NPK fertilizations significantly increased the stem height of Jew's mallow. The application of 9.52 Mg zeolite ha^{-1} increased the stem height from 17.4 cm in the control to 22.2 or 26.4 cm, respectively in clay soil and from 11.8 cm to15.1 or 17.9 cm, respectively in sandy soil. The highest values of stem height for clay and sandy soils (27.49 and 18.68 cm, respectively) as an average of spring and summer seasons were achieved with the application of 9.52 Mg zeolite ha^{-1}+ 100% NPK. While the treatment 50% NPK without zeolite gave the lowest values of stem for clay and sandy soils (16.6 and 11.3 cm, respectively). The increase of stem height might be due to stability of cell walls with zeolite. Also, the chemical fertilizer stimulates formation of new leaves and increases the size and height of plant. The obtained results are in agreement with those obtained by [39, 40] they found that 20% zeolite increased significantly all measured parameters, [21, 22] observed positive effect of chemical fertilizers on plant growth.

Table (6) Effect of zeolite and NPK fertilization on Jew's mallow stems height (cm)

Seasons	Soil types	Clayey soil				Sandy soil			
	Treatments	Zeolite app. (Z)			Mean	Zeolite app. (Z)			Mean
	NPK Fer. (F)	Z_0	Z_1	Z_2	(F)	Z_0	Z_1	Z_2	(F)
Spring	50%	16.48	21.02	24.97	20.82	11.2	14.28	16.97	14.15
	100%	17.96	22.91	27.22	22.70	12.21	15.57	18.5	15.43
	Mean (Z)	17.22	21.97	26.10		11.71	14.93	17.74	
(Z) F-test & $LSD_{0.05}$		** (0.09)				** (0.18)			
(F) F-test & $LSD_{0.05}$		** (0.04)				** (0.09)			
(Z*F) F-test		**				**			
Summer	50%	16.81	21.44	25.47	21.24	11.42	14.57	17.31	14.43
	100%	18.32	23.37	27.76	23.15	12.45	15.88	18.87	15.73
	Mean (Z)	17.57	22.41	26.62		11.94	15.23	18.09	
(Z) F-test & $LSD_{0.05}$		** (0.11)				** (0.21)			
(F) F-test & $LSD_{0.05}$		** (0.06)				** (0.13)			
(Z*F) F-test		**				**			

Z_0: without Zeolite addition; Z_1: 4.76 Mg zeolite ha^{-1}; Z_2: 9.52 Mg zeolite ha^{-1}.

3.3.2. Total fresh yield (Mg ha^{-1})

Data presented in Table (7) indicated that application of zeolite and NPK fertilization significantly increased total fresh yield of Jew's mallow. The application of 9.52 Mg zeolite ha^{-1} increased the fresh yield to 18.97 Mg ha^{-1} in clay soil and 10.15 Mg ha^{-1} in sandy soil comparing to the control in both soils

(15.15 and 7.99 Mg ha^{-1}, respectively) as an average between spring and summer seasons. The results revealed also that the highest values of the fresh yield in clay and sandy soils (19.53 and 10.44 Mg ha^{-1}, respectively) were recorded with application of 9.52 Mg zeolite ha^{-1} + 100% NPK followed by 9.52 Mg zeolite ha^{-1}+ 50% NPK in both soils (17.46 and 9.20 Mg ha^{-1}, respectively). While the treatment 50% NPK gave the lowest yields of Jew's mallow yield in both soils (14.66 and 7.73 Mg ha^{-1}, respectively) as an average between spring and summer seasons. The positive effect of zeolite fertilization on yield and its components may be attributed to hold nutrients in the root zone of plants [41, 42]. Also, [21, 22] reported the positive effect of the chemical fertilization on plant growth.

Table (7). Effect of zeolite and NPK fertilization on total fresh Jew's mallow yield (Mg ha^{-1})

Seasons	Soil types	Clayey soil				Sandy soil			
	Treatments	Zeolite app. (Z)			Mean	Zeolite app. (Z)			Mean
	NPK Fer. (F)	Z_0	Z_1	Z_2	(F)	Z_0	Z_1	Z_2	(F)
Spring	50%	14.76	16.27	17.94	16.32	7.53	8.30	9.15	8.33
	100%	15.50	17.09	18.84	17.14	7.91	8.72	9.61	8.75
	Mean (Z)	15.13	16.68	18.39		7.72	8.51	9.38	
(Z) F-test & $LSD_{0.05}$		** (0.053)				** (0.026)			
(F) F-test & $LSD_{0.05}$		** (0.027)				** (0.017)			
(Z*F) F-test		**				**			
Summer	50%	14.55	16.70	18.9	16.72	7.93	9.27	10.56	9.25
	100%	15.80	17.83	20.21	17.95	8.59	9.67	11.27	9.84
	Mean (F)	15.18	17.27	19.56		8.26	9.47	10.92	
(Z) F-test & $LSD_{0.05}$		** (1.72)				** (0.508)			
(F) F-test & $LSD_{0.05}$		ns				** (0.139)			
(Z*F) F-test		*				**			

Z_0: without Zeolite addition; Z_1: 4.76 Mg zeolite ha^{-1} ; Z_2: 9.52 Mg zeolite ha^{-1}.

4. CONCLUSION

It could be concluded that the use of Zeolite with NPK fertilization in clayey and sandy soils improved the soil properties, *ie.* decreased SARe, increased soil porosity and improved the availability of soil nutrients and consequently decreased the environmental pollution. In addition, the yield of Jew's mallow were increased in both soils by 33.25% and 35.13%, respectively comparing to the untreated soils. Also, the Zeolite as a natural material can be safely used for sustainable land use. Finally, the obtained results are promising for enhancing the horizontal and/or vertical expansion of agriculture in such problematic soils.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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