Original Research Article

Using zeolite and vermicompost amendments to iImprove water productivity of wheat irrigated by low-quality water in the Northern Nile Delta.

ABSTRACT

Aims: In the long run, reusing low-quality water in Egypt's agricultural sector directly or after mixing with fresh water to compensate for water supply constraints can be hazardous to plants and soil. As a result, some appropriate management must be considered. For this reason, a field experiment was implemented in winter seasons 2018/2019 and 2019/2020 at Sakha Agric. Res. Station Farm, Kafr El-Sheikh Gov., Egypt. This study aims to assess the impacts of zeolite and vermicompost as well their combinations on alleviation of low-quality water impacts on physicochemical properties of clayey soil and wheat productivity.

Study design: complete randomized block design with three replicates.

Results: The application of 2.40 Mg Z ha^{-1} was found to be the most effective on soil properties and plant growth. This treatment reduced soil EC, Na^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, and ESP values the most (52.90 percent, 83.21 percent, 30.43 percent, 6.04 percent, 91.82 percent, 19.83 percent, and 70.73 percent, respectively), while increasing K^{+} value by 32.47 percent. It also achieved the highest increases in plant height, 1000-grain weight, grain, and straw yields (35.92%, 9.60%, 42.77%, and 25.61%, respectively) when compared to untreated soil. With 2.40 Mg VC ha^{-1}, the greatest changes in bulk density, total porosity, and CEC (-9.23, 9.30, and 10.54 percent, respectively) were obtained. The applications of 1.80 Mg Z with 0.6 Mg VC ha^{-1} and 0.6 Mg Z ha^{-1} with 1.80 Mg VC ha^{-1}, on the other hand, resulted in the greatest increases in soil moisture content, drainable pores (DP), and water holding pores (WHP). Furthermore, 0.6 Mg Z combined with 1.80 Mg VC ha^{-1} significantly increased the available N, P, and K in the soil. The addition of 2.4 tons Z/ha increased the WP and resulted in a high economically appealing wheat.

Conclusion: It could be concluded that the application of Z and VC is a new strategy for alleviating abiotic stress and improving wheat growth. Z application was more effective than VC on improving soil physicochemical properties and improving the water productivity and achieve high economical attractiveness wheat irrigated by low-quality water.

Keywords: Low-quality water, Zeolite, Vermicompost, wheat productivity, physicochemical properties.

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1. INTRODUCTION

Water shortage in semi-arid regions is at risk, not only due to climate change but also due to human activities and changes in land use [1]. using low-quality water in irrigate agricultural land cause negative impacts on soil characteristics and ensure sustainable agriculture [2]; [3]; [4]; [5]; [6]; [7]. In Egypt, the available freshwater is limited and less than the present water demands. For this reason, using low-quality water in the agricultural sector directly or mixing with freshwater to extend the limited water supplies [8]; [9] and [10].

In general, some approaches have been applied to alleviate the bad effect of low-quality water on soil and crops such as natural zeolites (Z) as an ion exchanger and adsorbent [11] and the organic amendments [12]; [13]. Shape, dimensions, and linkage of Z pores are the key to its characteristics, where water and nutrients are stored and exchanged

[14]; [15] and [16]. Rahayu et al. [17] showed that the irrigation by saline water increased soil EC and SAR, whereas Z application decreased both parameters. Also, Z as soil amendments decreased soil ECe, SAR, and bulk density increased soil CEC and total porosity [18] and can improve soil quality immensely, through increasing water holding capacity and CEC [19] and increasing soil infiltration rate and water content [20].

Comment [AT2]: Improper parenthetical citation

On the other hand, vermicompost (VC) is a humus material produced from organic wastes through biodegradation by the action of earthworms [21]; [22]; and [5]. It can improve soil health status, enhance crop production and improve soil physical properties [24] and [25]. Also, it retains nutrients for a long time and has a high water-holding capacity and high porosity due to its humus content [26] and [27]. Also, VC significantly increased soil fertility, organic matter, total N, available P, exchangeable K, Ca and Mg, available S, Zn and B [28] and [29]. [30] demonstrated that using 10 Mg VC ha^{-1} increased soil N by about 42%, P by about 29%, and K by 57%. Also, VC significantly decreased the soil salinity, alkalinity, Cl^- and Na^+ while OM, CEC, and available nutrients (N, P, and K) were increased [31]; [32]; [33]; [34] and [35]. Soil physical properties were positively influenced by VC treatment, where the soil bulk density values were decreased, while available water capacity and total porosity were increased [36]; [37]; [38] and [39]. In addition, the growth and productivity of wheat were positively affected by VC application [40]; [41] and [42]. Therefore, this study mainly focused on the alleviation impacts of Z and VC amendments on physicochemical properties of clay soil and wheat productivity due to irrigation by low-quality water.

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2. MATERIAL AND METHODS

2.1. Study Site: A field experiment was implemented in two winters growing seasons (2018/2019 and 2019/2020) at Sakha Agric. Res. Station Farm, Kafr El-Sheikh Gov., Egypt (Latitude: 31° 05' 34.6" N/ Longitude: 30° 56' 55.24" E) to assess the alleviation of irrigation by low-quality water impacts on physicochemical properties of clay soil and wheat productivity by Z and VC amendments. The experimental field was prepared and the treatments were arranged in 24 plots (3x3 m for each) as complete randomized block design with three replicates. The treatments were as follows:

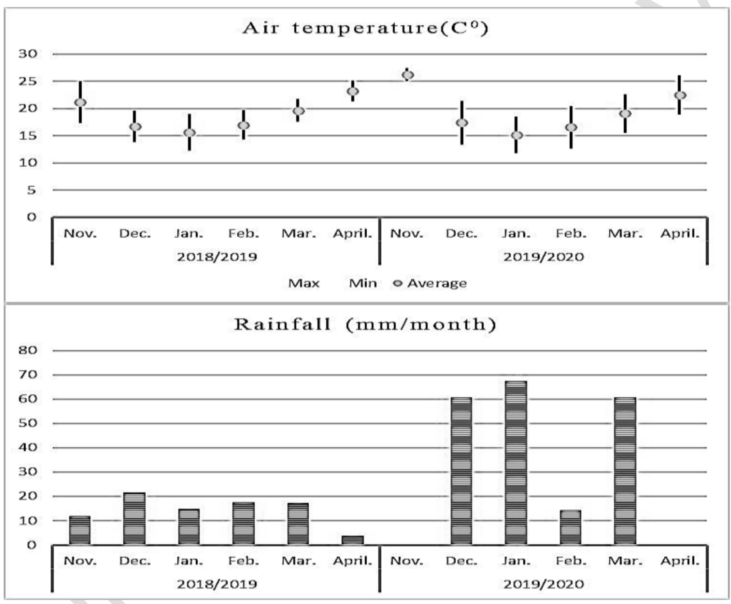
No	**Symbol**	**Treatments**
1	**CK**	Untreated soil (control)
2	**Z_1**	Zeolite applied at a rate of 1.20 Mg ha^{-1}
3	**Z_2**	Zeolite applied at a rate of 2.40 Mg ha^{-1}
4	**VC_1**	Vermicompost applied at a rate of 1.20 Mg ha^{-1}
5	**VC_2**	Vermicompost applied at a rate of 2.40 Mg ha^{-1}
6	**Z_1+VC_1**	Zeolite: Vermicompost 1.20:1.20 Mg ha^{-1}
7	**Z_3+VC_4**	Zeolite: Vermicompost 1.80: 0.60 Mg ha^{-1}
8	**Z_4+VC_3**	Zeolite: Vermicompost 0.60:1.80 Mg ha^{-1}

2.2. Cultural practices: Z (naturally volcanogenic sedimentary mineral and the major building blocks of Z are crystalline tetrahedrons of $[SiO_4]^{4-}$ and $[AlO_4]^{5-}$) was obtained from the A &O Trading Company at Hadaek Al-Ahram, Giza Gov., Egypt. While the VC was obtained from Central Lab. Of the Agric. Climate, Agric. Res. Center, Giza, Egypt. Z and VC were thoroughly mixed with the surface layer (0-30 cm) before cultivation. The chemical composition of Z and VC are listed in Table (1).

Experimental soil was divided into 24 plots. Wheat (*Triticum aestivum, L.*) variety (*Sakha 95*) grains were obtained from the Field Crops Research Institute, Sakha Agric. Res. Station, Kafr El-Sheikh Gov., Egypt, and planted at a seeding rate of 120 kg ha^{-1} on Nov. 20th, 2018 in the 1st season and Nov. 23rd, 2019 in the 2nd season. Fertilization and other agricultural practices were performed according to the Ministry of Agric. Recommendations for wheat in the North Delta. The average air temperature and rainfall during the wheat-growing period of 2018/019 and 2019/020 is shown in Fig.1

Table 1: Some chemical composition of zeolite and vermicompost.

Zeolite		**Vermicompost**	
SiO_2 %	72.90	pH (1:10)	7.62
Al_2O_3 %	11.95	EC_e dS m^{-1} (1:10)	4.59
CaO %	5.75	Organic matter (%)	31.92
K_2O %	4.10	Organic carbon (%)	18.56
Fe_2O_3 %	1.65	C/N ratio	11.46
MgO %	1.50	CEC (cmol kg^{-1})	272
Na_2O %	1.85	N%	1.62
TiO_2 %	0.30	P%	1.26
CEC (cmol kg^{-1})	150	K%	1.01
Volume density (kg m^3)	1780		



*max = maximum, min = minimum.

Fig.1. Average air temperature and rainfall during the wheat-growing seasons (2018/019 and 2019/020) from Sakha Agrometeorological Station, Kafr El-Sheikh Gov., Egypt.

2.3. Soil sampling and analysis: Soil samples were collected from the surface layer (0-30 cm) from each plot before and after the experiment. Samples were air-dried, crushed, sieved to pass through a 2.0 mm sieve, and homogenized. Irrigation water and soil physicochemical characteristics were analyzed according to the standard methods outlined by [43]**;** [44]**;** [45]**,** and [46] as shown in Tables (2).

2.4. Yield and Its Parameters: At maturity, plant height, 1000- grain weight, grain yield, and straw yield were measured in one m^2 area of each plot.

Table 2: Some chemical and physical characteristics of soil and irrigation water used before the experiment.

Chemical characteristics				Physical characteristics		
	Soil		Irr. Water			
Seasons	1st	2nd		Seasons	1st	2nd
pH*	7.89	7.93	7.08	Particle size distribution (%)		
EC (dS m^{-1})*	4.12	4.67	2.17	Sand	17.64	17.69
ESP*	12.88	13.90		Silt	24.12	24.03
Soluble ions (mmol. L^{-1})				Clay	58.24	58.28
Na^+	25.33	28.63	13.30	Texture class	Clayey	Clayey
K^+	0.44	0.42	0.42	Organic matter (%)	1.18	1.11
Ca^{2+}	9.74	10.83	5.03	Bulk density (g cm^{-3})	1.42	1.41
Mg^{2+}	5.62	6.05	2.82	Total porosity (%)	46.42	46.79
HCO_3^{--}	3.50	4.00	4.00	$CaCO_3$ (g kg^{-1})	1.86	1.69
Cl^-	22.14	24.33	11.31	CEC (cmol kg^{-1})*	42.33	42.48
SO_4^{2-}	15.49	17.62	6.26	Soil moisture characteristics (%)		
Available macronutrients (mg Kg^{-1})				Field capacity	42.95	43.19
N	28.16	29.19		Wilting point	22.34	22.92
P	7.53	7.47		Available water	20.61	20.27
K	227.24	231.28				

***pH**: was determined in soil water suspension (1:2.5); **EC**: was determined in saturated soil paste extract; **ESP:** Exchangeable Sodium Percent; **CEC:** Cation Exchange Capacity.

2.5. Water productivity (WP):

WP: is a partial-factor productivity that measures how the systems convert water into goods and services [47]. Its generic equation is:

$$WP = \frac{output\ derived\ from\ water\ use}{Water\ input}$$

2.6. Economic efficiency (Ee):

Ee was calculated according to [48] as follow:

$$\mathrm{Ee} = \frac{\text{Net return } (return - cost)}{\text{Applied irrigation water}}$$

2.7. Economic evaluation:

The economic evaluation profitability was calculated according to the equations outlined by [49] as follows:

$$\text{Gross revenue} = (\text{Grain yield} \times \text{price}) + (\text{Straw yield} \times \text{price})$$

$$\text{Net return (NR)} = \text{Total return} - \text{Total cost.}$$

$$\text{Benefit} - \text{cost ratio (BCR)} = \frac{\text{Net return (NR)}}{\text{Total cost.}}$$

2.8. Statistical analysis: One-way analysis of variance (ANOVA) using PROC GLM of SAS 9.00, data was analyzed. Duncan's multiple range test (DMRT) was used for comparison among the treatment means ($P < 0.05$) according to [50].

3. RESULTS

3.1. Soil chemical Characteristics:

When compared to the initial soil properties, the addition of Z and VC amendments influenced soil chemical properties ($P < 0.05$). The soil EC, ESP (Table 3), and soluble ion results are shown in Fig (1). According to the data, the application of Z and/or its combination achieved the best alleviation of the negative impacts on soil chemical characteristics caused by irrigation with low-quality water. The application of 2.40 Mg Z ha^{-1}

(Z_2) was the most effective treatment, as it reduced soil EC, Na^+, Ca^{2+}, Mg^{2+}, Cl-, SO_4^{2-}, and ESP values by 52.90 percent, 83.21 percent, 30.43 percent, 6.04 percent, 91.82, 19.83 percent, and 70.73 percent, respectively. When compared to CK, the K^+ value increased by 32.47 percent, followed by Z_3+V_4, Z_1+VC_1, and Z_1, but there were no significant differences between the Z_2 and Z_3+V_4 treatments. When compared to soil treated with Z alone, the application of VC alone resulted in a slight reduction in soil EC, ESP, and soluble ions. The changes in ECe and ESP for different treatments compared to the initial values revealed that the Z_2 treatment achieved the greatest decreases in ECe and ESP (69.88 percent and 109.24 percent, respectively), followed by Z_3+V_4 (60.58 percent and 102.29 percent, respectively), while CK plots recorded the greatest increases (11.11 percent and 3.56 percent , respectively).

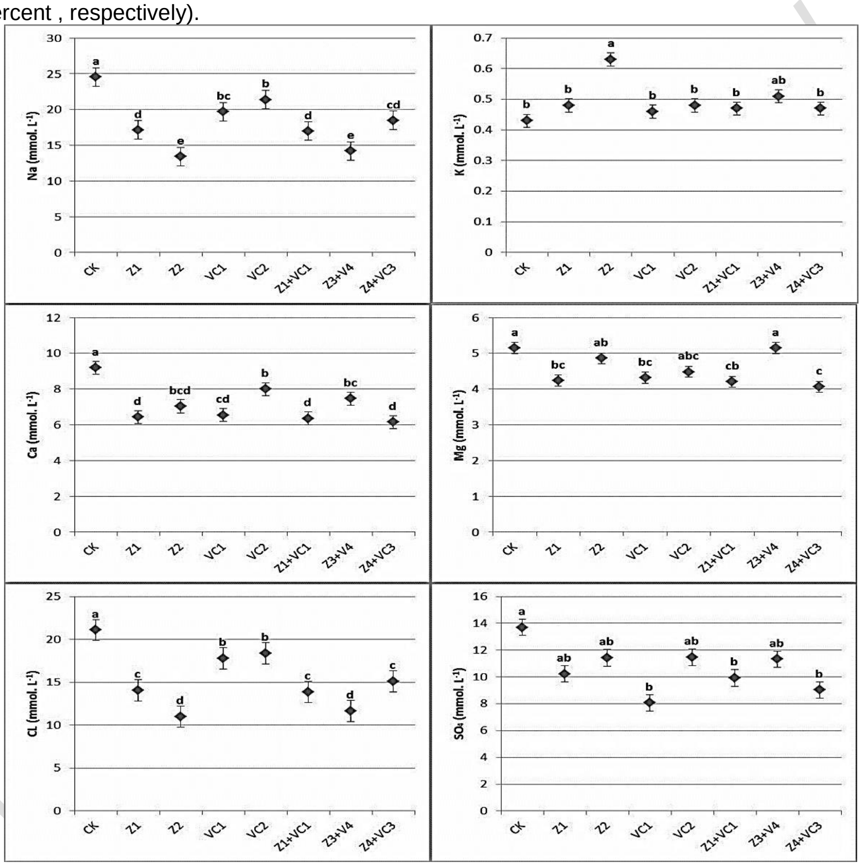


Fig.2. Effect of different rates of zeolite, vermicompost and their combinations on soluble ions. CK: Untreated soil (control), Z_1: Zeolite applied at a rate of 1.20 Mg ha^{-1}, Z_2: Zeolite applied at a rate of 2.40 Mg ha^{-1}, VC_1: Vermicompost applied at a rate of 1.20 Mg ha^{-1}, VC_2: Vermicompost applied at a rate of 2.40 Mg ha^{-1}, Z_1+VC_1: Zeolite: Vermicompost 1.20:1.20 Mg ha^{-1}, Z_3+VC_4: Zeolite: Vermicompost 1.80: 0.60 Mg ha^{-1} and Z_4+VC_3: Zeolite: Vermicompost 0.60:1.80 Mg ha^{-1}, respectively. Different letters on the top of the bars indicate significant differences at $P < 0.05$.

As a result, the CEC value in Ck plots was the lowest, while the highest value was obtained with VC2 treatment. Furthermore, VC outperformed Z in terms of CEC parameter improvement, while their combinations were less effective. The highest change in CEC value compared to the initial values (10.54 percent) exists with 2.40 Mg VC ha^{-1} (VC2), followed by Z_1+VC_1 and Z_4+VC_3 (8.29 and 8.28 percent, respectively), while CK had the lowest change (0.14 percent) (Table 3).The soil treated with 0.6 Mg Z combined with 1.80 Mg VC ha^{-1} (Z_4+VC_3) increased the available N, P, and K values (29.45, 63.20, and 51.06 percent, respectively) over the initial soil; however, insignificant differences in available N were found between VC_2, Z_3+V_4, and Z_4+V_3 and between VC_2 and Z_4+VC_3 on available P. (Table 3).

Table 3: Some soil chemical properties as affected by different treatments after both growing seasons.

Soil amendment	ECe dS m^{-1}	ESP %	CEC cmol kg^{-1}	Av. N mg kg^{-1}	Av. P mg kg^{-1}	Av. K mg kg^{-1}
CK	3.96±0.06^{a}	12.93±0.08^{a}	42.47±1.98^{c}	29.81±1.61^{d}	7.59±0.28^{f}	236.58 ±12.61^{f}
Z_1	2.81±0.13^{cd}	8.83±0.21^{c}	43.09±1.86^{bc}	30.51±1.17^{cd}	8.64±0.19^{e}	242.98±13.79^{ef}
Z_2	2.59±0.22^{d}	6.40±0.30^{d}	45.35±0.75^{ab}	31.92±1.86^{cd}	10.08±0.88^{dc}	266.64±10.12^{cd}
VC_1	3.10±0.08^{bc}	10.06±0.15^{b}	45.71±1.61^{ab}	32.37±2.36^{cd}	9.24±0.31^{e}	250.01±2.98^{def}
VC_2	3.45±0.50^{b}	10.19±0.64^{b}	46.88±1.53^{a}	35.52±0.57^{ab}	11.52±0.24^{ab}	284.20±14.57^{c}
Z_1+VC_1	2.75±0.08^{cd}	8.78±0.17^{c}	45.93±1.30^{ab}	33.30±0.97^{bc}	9.36±0.37^{de}	262.16±19.24^{cde}
Z_3+VC_4	2.74±0.12^{cd}	6.62±0.15^{d}	43.26±1.29^{bc}	36.34±2.12^{a}	10.80±0.34^{bc}	308.20±4.89^{b}
Z_4+VC_3	2.91±0.17^{cd}	9.74±0.42^{b}	45.92±1.44^{ab}	37.13±1.46^{a}	12.24±0.47^{a}	346.31±14.62^{a}
$LSD_{0.05}$	0.38	0.55	2.62	2.80	0.75	21.90

* Different upper case letters indicate significant differences between treatments (one-way ANOVA) for treatments, LSD test, (0.05)

3.2. Soil physical characteristics, moisture content, and pore size distribution %:

The mean values of bulk density (BD) and soil total porosity (TP) with different treatments are given in Table (4). In general, BD and TP were significantly affected by soil amendments compared to the control ($p<0.005$). The highest BD value and the lowest TP values were recorded in Ck plots while the lowest BD value and the highest TP values were achieved with VC_2 treatment. Moreover, VC improved BD and TP better than Z, while their combinations were less effective on both parameters. The highest changes in BD and TP values compared to their initial values (-9.23% and 9.30%, respectively) were achieved with 2.40 Mg VC ha^{-1} (VC_2) followed by application of 0.6 Mg Z ha^{-1} combined with 1.80 Mg VC ha^{-1} (-8.12% and 8.22%, respectively), while the lowest changes in both parameters (-1.67% and 1.47%, respectively) were recorded with CK.

Table 4: Soil BD and T.P values as affected by different treatments after both growing seasons.

Soil amendment	BD (g cm^{-3})	T.P %
CK	1.40 ± 0.02^{a}	47.30 ± 0.78^{e}
Z_1	1.37 ± 0.02^{ab}	48.43 ± 0.79^{de}
Z_2	1.35 ± 0.02^{bc}	49.06 ± 0.65^{cd}
VC_1	1.33 ± 0.02^{bcde}	49.69 ± 0.79^{abcd}
VC_2	1.30 ± 0.02^{d}	50.94 ± 0.76^{a}
Z_1+VC_1	1.32 ± 0.02^{cde}	50.19 ± 0.76^{abc}
Z_3+VC_4	1.34 ± 0.02^{bcd}	49.43 ± 0.76^{bcd}
Z_4+VC_3	1.31 ± 0.01^{ed}	50.44 ± 0.43^{ab}
$LSD_{0.05}$	0.033	1.25

* Different uppercase letters indicate significant differences between treatments (one-way ANOVA) for treatments, LSD test, (0.05).

The moisture retention curves of the soil treated by Z and VC as well as their combinations showed a relative increase in soil moisture content at medium suctions compared to that in CK plots (Fig.3). The highest increases in soil moisture content, drainable pores (DP), and water holding pores (WHP) were achieved with the application of 1.80 Mg Z ha^{-1} combined with 0.6 Mg VC ha^{-1} (Z_3+VC_4) and the application of 0.6 Mg Z ha^{-1} combined with 1.80 Mg VC ha^{-1} (Z_4+VC_3).

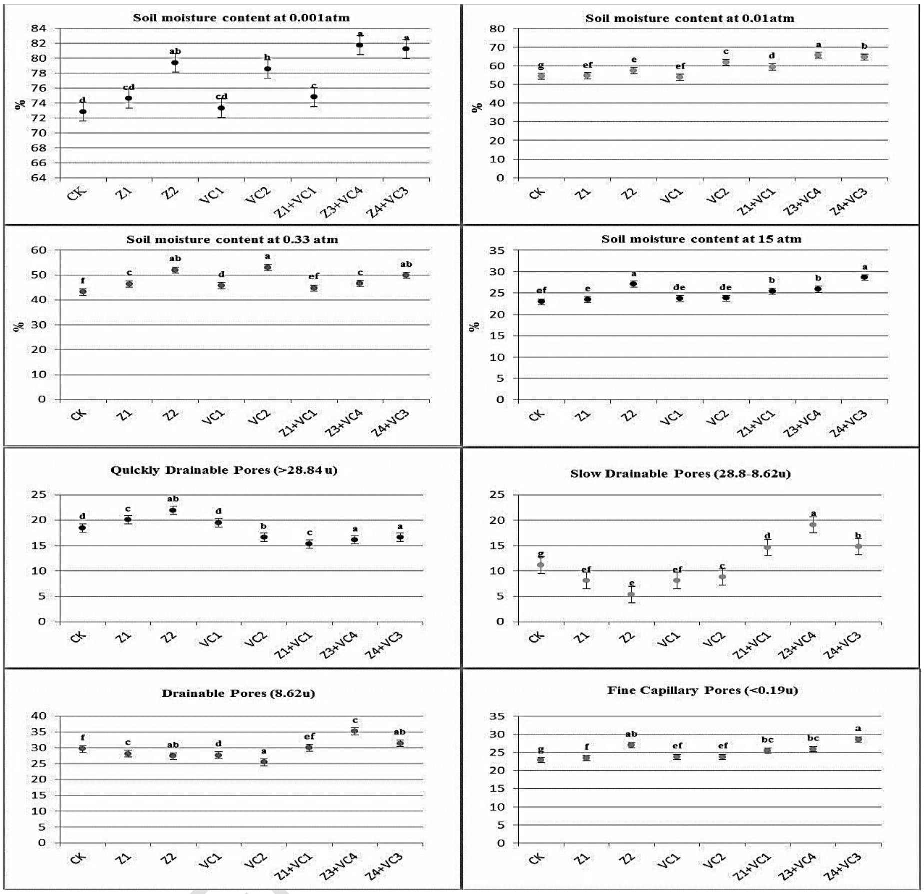


Fig.3. Effect of different rates of zeolite, vermicompost and their combinations on soil moisture content and pores size distribution after both seasons. Different letters on the top of the bars indicate significant differences at $P < 0.05$.

3.3. Growth and yield of wheat:

The data in Table (5) indicated that the soil amendments significantly improved wheat yield and growth parameters. The application of Z_2 treatment achieved the highest mean values of plant height (95.18 cm), 1000- grain weight (49.69 g), grain yield (8.80 Mg ha^{-1}), and straw yield (10.59 Mg ha^{-1}) followed by Z_3+VC_4 and Z_1+VC_1. However, there were insignificant differences between all treatments on wheat straw yield. Overall changes in wheat growth ($p \leq 0.05$) showed that Z_2 treatment increased plant height, 1000- grain weight, grain yield, and straw yield by 35.92%, 9.60%, 42.77%, and 25.61%, respectively, while the lowest increases (3.27%, 5.63%, 8.65%, and 2.16%, respectively) were obtained with VC_1 over their values in the untreated soil (CK).

Table 5: The yield and growth parameters of wheat in both seasons as affected by different treatments.

Seasons	Soil amendments	G.Y (Mg ha^{-1})	S.Y (Mg ha^{-1})	Plant height (cm)	1000-G.W (g)
2018/2019	**CK**	5909 ± 239^{d}	8018 ± 631^{a}	70 ± 1.53^{d}	45.18 ± 1.42^{b}
	Z_1	6742 ± 393^{c}	8773 ± 352^{a}	77 ± 2.52^{bcd}	47.34 ± 2.03^{ab}
	Z_2	8460 ± 549^{a}	10360 ± 197^{a}	94 ± 9.29^{a}	49.55 ± 1.55^{a}
	VC_1	6430 ± 325^{cd}	8460 ± 197^{a}	73 ± 4.04^{cd}	46.66 ± 2.27^{ab}
	VC_2	7575 ± 312^{b}	9215 ± 271^{a}	84 ± 9.29^{abc}	47.95 ± 2.38^{ab}
	Z_1+VC_1	7992 ± 508^{ab}	9449 ± 201^{a}	88 ± 5.13^{ab}	48.70 ± 1.90^{ab}
	Z_3+VC_4	8070 ± 251^{ab}	9658 ± 195^{a}	88 ± 8.02^{ab}	49.12 ± 1.44^{a}
	Z_4+VC_3	7809 ± 234^{ab}	9059 ± 111^{a}	84 ± 5.00^{abc}	48.17 ± 1.53^{ab}
	$LSD_{0.05}$	**639.39**	**2522.4**	**10.83**	**3.20**
2019/2020	**CK**	6143 ± 316^{d}	8851 ± 520^{a}	72 ± 1.53^{d}	46.22 ± 1.41^{b}
	Z_1	7081 ± 385^{c}	9085 ± 471^{a}	81 ± 3.61^{bcd}	48.42 ± 2.04^{ab}
	Z_2	8747 ± 563^{a}	10829 ± 458^{a}	99 ± 8.96^{a}	50.62 ± 1.54^{a}
	VC_1	6664 ± 385^{cd}	8773 ± 361^{a}	77 ± 4.16^{cd}	47.73 ± 2.26^{ab}
	VC_2	7861 ± 352^{b}	9814 ± 162^{a}	88 ± 10.58^{abc}	49.02 ± 2.40^{ab}
	Z_1+VC_1	8174 ± 597^{ab}	9462 ± 204^{a}	92 ± 3.79^{ab}	49.78 ± 1.89^{ab}
	Z_3+VC_4	8304 ± 251^{ab}	9684 ± 192^{a}	93 ± 8.51^{a}	50.20 ± 1.45^{a}
	Z_4+VC_3	8096 ± 197^{ab}	9033 ± 123^{a}	89 ± 4.58^{abc}	49.24 ± 1.54^{ab}
	$LSD_{0.05}$	**696.39**	**2185.6**	**11.16**	**3.20**

*G.Y= grain yield, S.Y= straw yield, 1000-G.W= 1000 grain weight. Different uppercase letters indicate significant differences between treatments (one-way ANOVA) for treatments, LSD test, (0.05).

3.4. Water productivity (WP):

As shown in Table (6), irrigation water productivity was increased significantly ($P< 0.05\%$) with the addition of 2.40 Mg zeolite ha^{-1} (Z_2). Z_2 achieved the highest WP values during the 1st and 2nd seasons (1.53 and 1.45kg m^{-3}, respectively). The lowest values in both seasons (1.07 and 1.02 kg m^{-3}, respectively) were recorded in the control. Also, WP was affected significantly at $P< 0.05\%$ of the VC application at different rates. The addition of 2.40 Mg vermicompost ha^{-1} (VC_2) produced higher values in both growing seasons (1.37 and 1.31kg m^{-3}, respectively). Therefore, WP values affected by Z and VC amendments were increased, according to the following descending order: $Z_2 > Z_3+VC_4 > Z_4+VC_3 > Z_1$.

3.5. Economic efficiency (Ee):

Regarding the effect of adds Zeolite and vermicompost on Ee was highly significant with Z_2 as compared with the other treatments. Both (Z_1+VC_1) and (Z_3+VC_4) treatments were similar in the two seasons as shown in Table 6. The lowest one 0.37 and 0.41 US$ m^{-3} were recorded under treatment CK (the control) for the same two seasons. Regarding the add Zeolite effect, results revealed that Ee increased significantly with increasing the addition of Zeolite in the following order $Z_2 > Z_1+VC_1 > Z_3+VC_4 > Z_4+VC_3$.

3.6. Net returns (NR):

Regarding the effect of adding Z and VC, the highest "NR" values in both seasons were occurred with Z_2 (1156 and 1566 US $ ha^{-1}, respectively), while the lowest (367 and 710 US$ ha^{-1}, respectively) were recorded with Kc. Consequently, NR values took the following order: $Z_2 > (Z_3+VC_4) > (Z_1+VC_1)$.

3.7. Benefit-cost ratio (BCR):

The effect of Z and VC on BCR is shown in Table 6. The analysis of variance revealed that the addition of Z highly significant effect on BCR at 5% level for the two seasons. The highest BCR in the 1st and 2nd seasons (0.67 and 0.88, respectively) were achieved with Z_2 and the lowest (0.22 and 0.41, respectively) were given in CK plots.

Table 6: Water productivity (WP), Economic efficiency (Ee), Gross revenue, Net return (NR), and Benefit-cost ratio (BCR) as affected by different treatments in both seasons.

Season	Treatment	WP_{GY} Kg m^{-3}	WP_{SY} Kg m^{-3}	Ee US$	G.R US$	Coast US$	NR US$	BCR US$
2018/2019	**CK**	$1.07±0.04^{d}$	$1.45±0.11^{a}$	$0.37±0.02^{d}$	$2049.51±87.72^{d}$	1682	$367.51±87.72^{f}$	$0.22±0.05^{e}$
	Z_1	$1.22±0.07^{c}$	$1.59±0.06^{a}$	$0.42±0.02^{c}$	$2319.67±105.03^{c}$	1702	$617.67±105.03^{de}$	$0.36±0.06^{cd}$
	Z_2	$1.53±0.10^{a}$	$1.87±0.04^{a}$	$0.52±0.03^{a}$	$2878.34±156.46^{a}$	1722	$1156.34±156.46^{a}$	$0.67±0.09^{a}$
	VC_1	$1.16±0.06^{cd}$	$1.53±0.04^{a}$	$0.40±0.02^{cd}$	$2216.97±81.73^{cd}$	1702	$514.97±81.73^{ef}$	$0.30±0.05^{de}$
	VC_2	$1.37±0.06^{b}$	$1.67±0.49^{a}$	$0.47±0.03^{b}$	$2574.18±160.91^{b}$	1842	$732.18±160.91^{cd}$	$0.40±0.09^{cd}$
	Z_1+VC_1	$1.45±0.09^{ab}$	$1.71±0.36^{a}$	$0.49±0.02^{ab}$	$2702.22±100.06^{ab}$	1782	$920.22±100.06^{bc}$	$0.52±0.06^{b}$
	Z_3+VC_4	$1.46±0.05^{ab}$	$1.75±0.35^{a}$	$0.49±0.01^{ab}$	$2734.43±42.33^{ab}$	1752	$982.43±42.33^{ab}$	$0.56±0.02^{b}$
	Z_4+VC_3	$1.41±0.04^{ab}$	$1.64±0.20^{a}$	$0.48±0.02^{b}$	$2631.66±119.28^{b}$	1812	$819.66±119.28^{bcd}$	$0.45±0.07^{bc}$
	$LSD_{0.05}$	**0.12**	**0.46**	**0.04**	**195.26**	**-**	**195.26**	**0.11**
2019/2020	**CK**	$1.02±0.05^{d}$	$1.47±0.09^{a}$	$0.41±0.02^{d}$	$2441.13±96.12^{d}$	1731	$710.13±96.12^{e}$	$0.41±0.06^{e}$
	Z_1	$1.18±0.06^{c}$	$1.51±0.08^{a}$	$0.45±0.02^{c}$	$2726.72±108.72^{c}$	1751	$975.72±108.72^{cd}$	$0.56±0.06^{cd}$
	Z_2	$1.45±0.09^{a}$	$1.80±0.08^{a}$	$0.55±0.03^{a}$	$3337.56±149.74^{a}$	1771	$1566.56±149.74^{a}$	$0.88±0.09^{a}$
	VC_1	$1.11±0.06^{cd}$	$1.46±0.06^{a}$	$0.43±0.01^{cd}$	$2583.53±81.85^{cd}$	1751	$832.53±81.85^{ed}$	$0.48±0.05^{ed}$
	VC_2	$1.31±0.06^{b}$	$1.63±0.27^{a}$	$0.50±0.02^{b}$	$3005.88±145.73^{b}$	1891	$1114.88±145.73^{cb}$	$0.59±0.08^{cd}$
	Z_1+VC_1	$1.36±0.10^{ab}$	$1.57±0.34^{a}$	$0.51±0.02^{b}$	$3067.63±137.20^{b}$	1831	$1236.63±137.20^{b}$	$0.68±0.08^{bc}$
	Z_3+VC_4	$1.38±0.04^{ab}$	$1.61±0.32^{a}$	$0.52±0.02^{b}$	$3121.99±88.09^{b}$	1801	$1320.99±88.09^{b}$	$0.73±0.05^{b}$
	Z_4+VC_3	$1.34±0.03^{ab}$	$1.50±0.21^{a}$	$0.50±0.03^{b}$	$3011.93±151.02^{b}$	1861	$1150.93±151.02^{cb}$	$0.62±0.08^{bc}$
	$LSD_{0.05}$	**0.12**	**0.36**	**0.04**	**212.7**	**-**	**212.7**	**0.12**

* WP_{GY}= grain yield, WP_{SY}= straw yield, Ee = Economic efficiency, NR= Net return and BCR= Benefit-cost ratio, G.R= Gross revenue has been calculated by multiplying total yield in kg ha^{-1} and wheat market price per kilogram, the farm-gate price for wheat grain in this study was 0.222 US$ kg-1 and 0.04 US$ for kilogram straw (Exchange rate 1 EGP=0.06 US$ in 2018). Different uppercase letters indicate significant differences between treatments (one-way ANOVA) for treatments, LSD test, (0.05).

4. Discussion

4.1. Soil chemical characteristics:

The data indicated that irrigation by low-quality water increased Na^+ and Cl^- concentration with different treatments. The addition of Z and its combinations were more effective in reducing EC, Na^+, Ca^{2+}, Mg^{2+}, Cl^- and ESP values. These results are in the same line with [18]**,** who reported that application of Z decreased soil ECe and SAR values. The irrigation by saline water increased soil salinity and alkalinity [51], whereas Z application decreased both parameters due to that Na^+ ions are adsorbed by the Z [17]. According to [52], the application of Z can reduce soil Na^+ content from 563.0 to 182.7 ppm.

Moreover, VC improved the soil CEC parameter better than Z. The increase of CEC values may be attributed to the high CEC of VC. Similar results are obtained by [36]; [37]; [38]; [39]; [41] and [42]. The contents of available N, P, and K were increased with the application of Z or VC as well as their combinations. These increases may be related to the high CEC and other characteristics in Z and VC, which improved soil fertility. These results are agreed with [14]; [53]; [15]; and [16] who reported that the application of Z was particularly useful in improving nutrient supply. Application of zeolite amendments increased soil potassium availability [54]. Also, using VC can increase available N, P, and K in the soil according to [31]; [30]; [32]; [28]; [29]; [33]; [55]; [34] and [35], who demonstrated that VC increased the beneficial microbial populations and thus improved soil fertility.

4.2. Soil physical Characteristics:

Application of VC improved BD and TP parameters better than Z. The decline in BD and increasing in TP values were probably due to forming of aggregates and macro-pores by VC. Similar results were obtained by [36]**;** [37]**;** [38]**;** [39]**;** [41] and [42].

The moisture retention curves of the soil treated by Z or VC and their combinations showed a relative increase in soil moisture content at medium suctions. These results are in harmony with that observed by [26]**;** [27]**;** [19]**;** [18] who reported that the soil treated with Z and VC significantly increased water holding capacity and soil water content. Also, [20] reported that the infiltration rate and soil water content were significantly increased in soil treated with Z.

4.3. Growth and yield of wheat:

The stimulation of wheat growth by adding Z is due to alleviating salinity stress and improving the nutrient supply to plants and consequently, it will reflect on plant production. Using Z as soil amendment increased the contents of macro and trace elements (Ca^{2+}, Fe^{2+}, and Mn^{2+}) in plants under salinity conditions [56]. On the other hand, [57] observed that Z significantly increases Ca^{2+} concentration in the plant; this leads to a decrease in the Na^+/Ca^{2+} ratio in plant tissues leading to higher tolerance to Na^+ cation. Also, [58] stated that Z as soil ameliorating amendments improved water holding capacity, availability of soil nutrients; improved infiltration rate, bulk density, soil porosity, and CEC, and also significantly increased crop production. According to [17], the application of Z in saline soil can control the availability of Na at a low level, thus the plant can grow well. [59] confirm that the yield increasing mechanism of Z saved the demands of plants for N during the entire growth period. On the other hand, VC can play an effective role in plant growth and also reduced the harmful effects of various environmental stresses on plants through its contents from microorganisms such as mycorrhizal fungi which enhances the water uptake by roots [60]. Also, the addition of VC to the root environment provides better conditions for the uptake of water and nutrients as well as better photosynthesis [61]. Most of the available nutrients for the plant are found in VC and thus it enhances the yield and quality-related traits of crops [62]. [63] reported that VC application improved crop growth and yield of wheat.

4.4. Water productivity (WP):

WP measures the relationship between the amounts of crop produced from the unit of irrigation water. Different water productivity indices result from different water input options. In the present study, the WP was calculated as a ratio between crop yields achieved with the addition of Z and VC. A higher WP resulted in either the same product from the same water resources, depending on the applied treatments. This might be due to under the zeolite application, the increase of yield and decrease in water consumption leads to improved water productivity [64]**;** [65]**;** [66]. Zeolite can be increased the water-holding capacity of water due to its crystalline structure [14]**;** [15] and [16].

4.5. Economic efficiency (Ee):

Ee takes into account values of output, opportunity costs of inputs, and externalities and is achieved when scarce resources (as well as in Egypt) are allocated and used such that net value or net returns (returns minus costs) are maximized [48]. Regarding the effect of adding Zeolite and vermicomposting on Ee was highly significant with addition of 2.40 Mg zeolite ha^{-1} (Z_2) as compared with the other treatments.

4.6. Net returns "NR":

Regarding the effect of addition Z and VC, the highest "NR" values in both seasons were occurred with Z_2 (1156 and 1566 US $ ha^{-1}, respectively), while the lowest (367and 710 US$ ha^{-1}, respectively) were recorded with Kc. Consequently, NR values took the following order: Z_2 > (Z_3+VC_4) > (Z_1+VC_1).

4.7. Benefit-cost ratio"BCR":

The results indicated that if good water was not available, low-quality water (2.17 ds/m) can be used with the addition of 2.4 tons Z /hectare to achieve a high economically attractive yield to reduce water permeation conditions in water-limited areas. The reason for this may be that the addition of Z led to improve the soil properties led to increase the total yield [18]. Also, zeolite amendment increased economic benefit by increase the rate to yield output [54].

5. CONCLUSION

It could be concluded that the application of Z and VC is a new strategy for alleviating abiotic stress and improving wheat growth. Z application was more effective than VC on improving soil physicochemical properties and improving the water productivity and achieve high economical attractiveness wheat irrigated by low-quality water.

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