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Productivity of Heavy Clay Soils as Affected by Some Soil Amendments Combined with Irrigation Regime

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TWO field experiments were carried out at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate during the two growing seasons 2015/2016 and 2016 to investigate the effect of irrigation regimes and soil amendments on some soil properties, some water relations and yields of wheat and maize. The experiments were conducted in strip block design with three replicates. The most important findings can be summarized as follows: Irrigation at 40% depletion of available soil moisture received the highest amount of irrigation requirements, consumed water and stored water. The highest values of irrigation application efficiency and water consumptive use efficiency were recorded with irrigation treatment at 55% depletion of available soil moisture (I_2) during two growing seasons. Water productivity (WP) and productivity of irrigation water (PIW), were recorded highest values under (I_2) for maize crop. While the highest values of WP and PIW for wheat and maize were achieved from the interaction between irrigation treatment (I_2) and soil amendments. The electric conductivity, sodium adsorption ratio, exchangeable sodium percentage were clearly improved and reducing of soil bulk density and increasing soil basic infiltration rate with application of soil amendments. Irrigation treatments and soil amendments have highly significant effect on increasing of yield of wheat and maize. Economic evaluation recorded the highest values of total income, net income, economic efficiency and net income from water unit with application of compost at rate of 5 ton fed^{-1} under I_2 for wheat and maize crops.

Keywords: Irrigation regimes, Soil amendments, Soil properties, Wheat, Maize, Clay soils.

Introduction

Soils with excess soluble salts or exchangeable sodium in the root zone are termed salt-affected soils. Owing to limited rainfall and high evapotranspiration demand, coupled with poor soil and water management practices, salt stress has become a serious threat to crop production in arid and semi-arid regions of the world (Munns 2002). Therefore, soil salinity causes plant stress in two ways: (1) making water uptake by the roots more difficult, and (2) causing plant toxicity via accumulation of high salt concentrations in the plant (Munns and Tester, 2008).

Generally, wheat (*Triticumaestivum* L.) and maize (*Zea mays* L.) are the most strategic crops for food, feed, and biofuel security worldwide (Naveed et al., 2014 and Hafez et al., 2019). Rapid population growth is applying great pressure to increase wheat and maize production and by 2050 consumers will require 60% more than today (Asseng et al., 2018). They consider the second and third most important cereal crops which grown under a wide spectrum of soil and climatic conditions.

Water deficit has been, for a long time, the main environmental factor that impedes plant growth and crop productivity globally (Begcy and Walia, 2015). Roughly 1.2 billion people are living with severe water deficit, and the water-limited regions are constantly expanding (Wouters 2011). Out of the total water use in the world, about 70% is used by the agricultural sector. In Africa, about 90% of the water goes towards agriculture (Vorosmarty

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et al., 2010). Water deficit is detrimental to plant growth and yield productivity, which rely substantially on irrigated ecosystems (Farooq et al., 2014). Also, sodium and magnesium have a negative effect on soil physical properties when its concentration is relatively high compared to calcium as well as the slow drawdown rate of the excess water through soil profile after irrigation indicated that the tile drainage system in Kafr El-Sheikh Governorate area is not efficient and or the soil compacted due to unfavorable chemical and physical (Amer et al., 2018). Therefore, there is an imminent need to increase crop production under water deficit. At present and more so in the future, the increment of water deficit will result in a greater focus on ameliorating excessive water use by introducing more efficient farming practices that will increase wheat production (Hafez et al., 2019). Therefore, good agricultural operation along with effective inputs and technology use, such as soil amendments. For instance, gypsum, sulphur, zeolite, compost and magnetite are the best tools to improve physiological processes and plant performance under water deficit conditions.

Gypsum ($CaSO_4$, $2H_2O$), is a naturally occurring mineral that is mined for many purposes. It has a calcium content at 23% and sulphur content of 19% and usually used for treating sodium affected soils on farm. The calcium in the applied gypsum enables sodium displacement in the cation exchange capacity of the soil. However, large amounts of calcium are required. Thus, it is a mass action process (Gelderman et al., 2004). The application of compost accelerated sodium leaching and reduced Electrical conductivity (EC), and improving of soil physical which increased water – holding capacity and soil aggregate stability (Tejada et al., 2006). Also, many studies showed that application of compost had positive effect on plant nutrients as well as led to remove Na^+ far from root zone (Abdel-Fattah and Merwad, 2016).

Zeolites are hydrated aluminosilicate of alkaline with open three-dimensional structure and are able to lose or gain water reversibly and exchange extra framework cations, both without crystal structure changes (Mumpton, 1999). Zeolites can act as water own weight, later on this water released slowly as per plant water demand, reduces surface erosion, prevent surface and ground water contaminations, cleans up earthen pits, prevent orders and nitrate leaching and for sequestering and releasing ammonia- N (Pisarovic et al., 2003; Gul et al., 2005).

On the other hand, magnetic iron is one of the most useful factors affecting plant growth. Magnetite has a black or brownish-red color, natural row rock that has very high iron content and its hardness of about 6 on the Moh's hardness scale. So, magnetite is one of two natural row rocks in the world that is naturally magnetic (Mansour 2007). It has been reviewed that the positive effect of magnetic treatment may be attributed to paramagnetic properties of some atoms in plant cells and some pigments such as chloroplasts. Magnetic properties of molecules determine their ability to attract and then change the energy of a magnetic field in other types of energy and to transform this energy to other structures in plant cells, thus activating them (Aladjadjiyan 2010), and play an important role in cation uptake capacity and have a positive effect on immobile plant nutrient uptake, such as Ca and Mg (Esitken and Turan 2004).

Hence, this research was implemented to estimate the individual role of soil amendments; gypsum, sulphur, zeolite, compost and magnetite on improved of some soil properties and yield – water productivity of wheat and maize plants.

Materials and Methods

A field trial was carried out at Sakha Agricultural Research station farm, Kafr El-Sheikh Governorate, Egypt. The experiment was conducted during winter season of 2015/2016 and summer season of 2016 to study the effect of different irrigation regimes, and soil amendments on some physical and chemical soil properties, some water parameters and yield of wheat and maize crops. The experiment was conducted in strip block design with three replications, the main plots were assigned to three irrigation regimes, 1) irrigation at 40% depletion of available soil moisture (I_1), 2) irrigation at 55% depletion of available soil moisture (I_2), and 3) irrigation at 70% depletion of available soil moisture (I_3), as well as, 10% as leaching requirement (LR) was applied for each irrigation treatment for the seasons. Whereas, subplots were devoted to six soil amendments, 1) control (without application), 2) gypsum (100% gypsum requirements (4.642 ton fed^{-1}), 3) sulphur (200 kg fed^{-1}), 4) zeolite (100 kg fed^{-1}), 5) compost (5 ton fed^{-1}), 6) magnetite (100kg fed^{-1}). All soil amendments were added before planting of wheat in the first growing season by mixed with the top 30 cm of soil field.

The plot area was 150 m^2 (30m length x 5 m width), and some physical and chemical characteristics of the experimental soil and compost used are presented in Table 1 as well as the meteorological data from Sakha Agricultural Research Station during the growing seasons are presented in Table 2.

TABLE 1. Some physical and chemical characteristics of the experimental soil and compost used.

Soil depth(cm)	Physical characteristics								
	Soil moisture characteristics				Particle size distribution (gkg-1)				
	F.C (%)	W.P. (%)	A.W. (%)	B.D. (kg m^{-3})	IR(cmh-1)	Sand	Silt	Clay	Soil texture
0-20	43.21	22.16	21.05	1.36		173.1	255.1	571.8	clay
20-40	40.62	20.48	20.14	1.39	0.45	188.5	247.6	563.9	clay
40-60	38.73	19.13	19.60	1.44		190.6	251.2	558.2	clay

Chemical characteristics

Soil depth(cm)	pH	EC (dSm^{-1})	SAR	ESP (%)	CEC (cmole kg^{-1})	OM (g kg^{-1})	$CaCO_3$ (gkg^{-1})
0-20	8.48	6.43	13.36	15.57	39.46	189	297
20-40	8.60	7.35	14.61	16.87	38.21	162	286
40-60	8.75	9.73	16.45	18.70	37.18	145	233
Mean	-	7.84	14.80	17.05	38.28	165	270

Compost characteristics

EC dsm^{-1}	PH	C %	OM %	C/N ratio	N	P	K	Fe	Zn	Mn	Moisture %
					%			ppm			
3.68	7.83	32.50	56.03	17.86	1.82	0.94	1.18	156	59	123	27.50

F.C.: Field Capacity**; W.P.:** Wilting Point; **A.W.**; Available Water; **B.D.**: Bulk Density; IR : infiltration rate. **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;**OM**: Organic Matter.

TABLE 2. Climatological data for the growing seasons in 2015/2016.

Month	Temp. (C°) Max.	Temp. (C°) Min.	R.H. (%)	W.V. (Km day^{-1})	P.E. (mm day^{-1})	Rain (mm)
			2015			
Nov.	24.40	14.42	75.6	70.30	3.19	52.40
Dec.	19.70	8.36	77.9	57.90	2.50	25.00
			2016			
Jan.	18.40	6.35	74.05	69.20	2.52	43.21
Feb.	22.58	9.35	69.05	58.80	2.52	-
Mar.	24.50	11.60	69.9	63.20	3.59	13.20
Apr.	30.03	18.62	61.7	87.10	5.94	-
May.	30.40	22.80	58.4	97.00	6.47	-
Jun.	33.60	26.30	61.15	112.80	8.07	-
July.	33.70	26.10	69.75	105.50	7.84	-
Agus.	33.60	26.00	70.30	92.80	7.74	-
Sept.	32.60	24.30	67.45	95.10	5.91	-

Temp.: Temperature; **R.H**.: Relative Humidity; **W.V**.: Wind Velocity (at 2 m height); **P.E.**: Pan Evaporation.

Grains used

Wheat (Giza 168) was sown on 20th November in 2015 and harvested on 25th April 2016 whereas;maize (Single hybrid 10) was sown on 15thMay, 2016 and harvested on 20th September 2016. The used grains were kindly supplied by Field Crops Research Institute, Sakha, Agricultural Research Station, Egypt.

Mineral fertilizers

Nitrogen, phosphorus and potassium fertilizers were added according to the recommended doses of north delta area by Egyptian Ministry of Agriculture and land reclamation.

Measurements

Soil samples were collected at depths namely 0-20,20-40 and 40-60cm before planting and after harvesting, then air, dried, ground and passed through 2mm sieve and preserved for analysis.

Some Soil physical properties

The textural class of soil was determined according to the pipette method as described by Dewis and Fartias (1970). Field capacity (F.C) and permanent wilting point (PWP) were determined using pressure membrane at 0.33 and 15atm (Klate, 1986).

Soil bulk density and total porosity of the different layers of soil profile in all plots was measured using the core sampling technique as described by Camphell (1994) Infiltration rate was determined using double cylinder infiltrometer as described by Garcia (1978).

Some soil chemical properties

Salinity was determined in saturated soil paste extract according to page et al. (1982). Exchangeable sodium percentage was determined using ammonium chloride and measured by using flame photometer according to page et al. (1982). Cation exchange capacity (CEC) was determined according to Richard (1954). Gypsum requirements was determined according to FAO and IIASA (2000).

Irrigation parameters

Determination of soil moisture percentage

Soil samples were taken from each depth interval up to 60cm before and after irrigation to determine moisture content and to calculate the amount of consumed water and stored water for each irrigation, according to Garcia (1978).

Soil chemical properties

Amount of irrigation water applied

It was measured by using a set of cuts- throat flumes (20 x 90 cm) according to Early (1975).

Water consumptive use (WCU)

Water consumptive use by growing plants was calculated based on soil moisture depletion (SMD) according to the following equation (Hansen et al., 1979).

$$WCU = \sum_{i=1}^{i=n} \frac{è_2 - è_1}{100} \text{ x Dbi x } \frac{D}{100} \text{ x } 4200$$

Where,WCU: water consumptive use (m^2/fed.) in the effective root zone, θ_2: Gravimetric soil moisture percentage after irrigation, θ_1: Gravimetric soil moisture percentage before next irrigation, Dbi: Soil bulk density (Mgm^{-3}), Di: Soil layer depth(m), I: Number of soil layers (1-4) Stored water in the effective root zone

Stored water was calculated using the following equation: (Hansen et al., 1979).

$$WS = \sum_{i=1}^{i=n} \frac{è_2 - è_1}{100} \text{ x Dbi x D x } 4200$$

Where, $è_2$: Soil moisture % after irrigation with 48 hours in the 1th layer, $è_1$: Soil moisture % before the same irrigation in the 1th layer, Dbi: Bulk density in (Mgm^{-3}) of other 1th layer

Irrigation application efficiency (Ea)

It is defined as a ratio %, between the amount of stored water ($m^3 fed^{-1}$) and the amount of the water applied ($m^3 fed^{-1}$) as described by Downy (1970).

Ea= (WS /Wa) x 100

Where: WS, Wa are the volumetric water stored and water applied.

Water productivity (WP)

It was calculated according to Ali et al. (2007).

WP=Gy/ET

Where, Gy: grain yield (kg fed^{-1}) and ET: Total water consumption of the growing season (m^3 fed^{-1})

Productivity of applied irrigation water (PIW)

It was calculated according to Ali et al. (2007).

PIW=GY/I

Where, I: irrigation water applied (m^3 fed^{-1})

Yield

Wheat plants samples were taken from all treatments for determinations of grains, straw yield (ton fed^{-1}), 1000-grain weight (g) and grains yield, stalk yield (ton fed^{-1}) and weight of 100 grain (g) were recorded after harvesting of maize crop.

Economic evaluation

Gross return (LE $Fed.^{-1}$), net return (LE $Fed.^{-1}$) and economic efficiency were used to run the economic evaluation.

Statistical analysis

The data were analyzed statistically by analysis of variance (ANOVA) using Cohort computer program according to Gomez and Gomez (1984). Mean separation procedure was performed using LSD, S test at a 0.05 and 0.01 level of significance.

Results and Discussion

In this study, some of physical and chemical soil properties, some water relations and yields of wheat and maize showed significant differences in response to soil amendments.

Soil amendments and soil physical properties

Soil bulk density (BD)

Data in Table 3 showed that the soil amendments effectively in decreased of soil bulk density especially under irrigation regimes. The mean value of soil bulk density before experiment was 1.39Mg m^{-3}. The highest reduction of BD values through the two growing seasons (after harvesting of wheat and maize crops) were recorded under compost, gypsum and zeolite as compared to other soil amendments treatments. BD values after wheat crop decreased by 9.35, 7.91, 6.47, 5.04 and 3.60% with compost, gypsum, magnetite and Sulphur treatment, whereas it decreased after harvesting of maize crop by 12.92, 11.51, 9.35, 7.91, 7.91 and 5.76% as compared with BD before experiment, respectively.

The application of gypsum, compost and mole drain to improve some physio-chemical properties of salt affected soil. The BD was clearly decreased due to application of gypsum with compost reduction were (5.4 and 7.4%) (Amer and Hashem 2018). So, the effect different treatments on soil bulk density followed the ascending order such as: compost > gypsum > zeolite > magnetite >Sulphur> control. The obtained results are similar to those reported (Hussain et al., 2001; Antar et al., 2008; Abdel-Fattah et al., 2016; Bayoumy et al., 2019).

Soil porosity

Results in Table 3, revealed that the application of compost, gypsum, zeolite, magnetite and Sulphur increased the soil porosity from 52.45, 51.70, 50.94, 50.19 and 49.43% after harvesting of wheat, the application of compost had positive effect on the soil porosity since it was increased to 52.45% and 54.34% after harvesting of wheat and maize crop, respectively as compared with before planting. Thus, the role of compost may be related to increase of soil granulation, increase porosity and decrease soil density and improving soil properties, EL-Henawy et al., (2016).

The data referred also that application of soil amendments under irrigation treatments I_1(irrigation at 40% depletion of available soil moisture with 10% as leaching requirements) had positive effect on increasing of the soil porosity after the first and second seasons (51.70%, 53.58%). The data cleared that application of compost had positive effect on EC_e due to improving the soil physical properties; hence it led to remove Na^+ fare from root zone. These results are in harmony with those obtained by Abdel-Fattah et al. (2016), Amer and Hashem, (2018) and Bayoumy et al. (2019). Finally, the effect of different soil amendments on soil porosity can be arranged in following ascending order compost> gypsum > zeolite > magnetite >Sulphur> control.

Soil basic infiltration rate (IR)

Infiltration rate (IR) is the volume flux of water flowing into the profile per unit of soil surface area. The data in Table 3, showed that the soil amendments effectively in increased of soil basic infiltration rate (IR) under Irrigation regimes. Also, results showed that the application of compost increased IR from 0.45 cm/h before planting to about 1.10 and 1.30 cm h^{-1} after harvesting wheat and maize. also, the data referred that the IR increased to 0.90 and 1.15 cm h^{-1} after first and second seasons, respectively as compared before planting. The effect of different soil amendments on soil basic infiltration rate (IR) can be arranged in following ascending ordercompost > gypsum > zeolite > magnetite >Sulphur> control. Saied et al., (2017) found that the positive effect of compost on decreasing of the bulk density and increasing the soil porosity and IR values, consequently ease leaching the salts from upper soil layer and movement far by mole drainage (Amer and Hashem, 2018).Finally, the application of soil different amendments treatments on improving soil health by enhancing soil quality parametersbulk density, soil porosity, aggregation, structure and water holding capacity. The obtained results are similar to those reported (Hussain et al., 2001; Antar et al., 2008; Abdel-Fattah et al., 2016; Amer and Hashem, 2018; Bayoumy et al., 2019).

TABLE 3. Effect of irrigation treatments and soil amendments on soil bulk density, total porosity and infiltration rate after cultivation of wheat and maize crops.

Treatments	Wheat			Maize		
	Bulk density (mg m^{-3})	Total porosity (%)	Infiltration rate (cm h^{-1})	Bulk density (mg m^{-3})	Total porosity (%)	Infiltration rate (cm h^{-1})
Irrigation treatments						
I1	1.26	52.45	1.10	1.21	54.34	1.30
I2	1.29	51.32	0.90	1.2.4	53.20	0.95
I3	1.33	49.81	0.75	1.28	51.70	0.85
Soil amendments						
Control	1.37	48.30	0.50	1.34	49.43	0.65
Gypsum	1.28	51.70	0.90	1.23	53.58	1.15
Sulphur	1.34	49.43	0.60	1.31	50.57	0.75
Zeolite	1.30	50.94	0.85	1.26	52.45	0.95
Compost	1.26	52.45	1.10	1.21	54.34	1.30
Magnetite	1.32	50.19	0.75	1.28	51.70	0.85

I$_{1:}$ Irrigation at 40% depletion of available soil moisture; **I**$_{2:}$ Irrigation at 55% depletion of available soil moisture; **I**$_{3:}$Irrigation at 70% depletion of available soil moisture.

Soil amendments and soil chemical properties

Soil salinity (ECe)

Data in Table 4 showed that the soil amendments under irrigation effectively in decrease of soil salinity (ECe) than before experiment instillation in the soil (0-60cm depth). The mean values of EC before experiment were 7.84 dS m^{-1}, respectively. The highest reduction of ECe values through the two growing seasons (after harvesting of wheat and maize crops) were recorded under gypsum rate 4 t.fed^{-1} and irrigation at 40% depletion of available soil moisture as comparing with other soil amendments. Ece values after wheat crop decreased by 23.98, 19.89, 13.90, 9.18, 7.39 and 4.46% with gypsum, zeolite, compost, magnetite, Sulphur and control treatments, whereas, it decreased after harvesting of maize crop by 42.35, 26.28, 21.56, 17.98, 12.63, and 9.18% as compared with Ece before experiment, respectively.

The studied treatments could be arranged in the following order; gypsum >zeolite >compost >magnetite >Sulphur >control. These results are in harmony with those obtained by Ali and Kahlown (2001), Ghaudhry (2001), Favaretto et al. (2006), Abdel-Fattah (2012), and Hafez et al. (2015). The effect of application on saline-sodic soil reclamation have shown that the soil receiving gypsum at higher rate removes the greatest amount of Na+ from the soil columns and causes a substantial decrease in soil electrical conductivity (EC) and sodium adsorption ratio (SAR). The obtained results seem to agree with Abdel-Fattah et al. (2012), Amer and Hashem (2018) and Bayoumy et al. (2019).

Also, data showed that the ECe in root zone was decreased due to application of zeolite after harvesting of wheat and maize crops (6.28 and 5.78 dS m^{-1}) with reduction of 19.89 and 26.28% respectively. Khuder et al. (2017) found that the positive improvement in soil physical, chemical and fertility characters because of zeolite addition, such as Ec prediction, which it reaches 35.48 and 28.40% compared with control. The obtained results seem to agree with Krutilima et al. (2000), Yamada et al. (2002), Turk et al. (2006), Al-Busaide et al. (2007). Moritani et al. (2010), Nasri(2012) and Najafinezhad et al. (2014), Amer and Hashem (2018) and Bayoumy et al. (2019).

The data cleared that application of compost had positive effect on ECe due to improving the soil physical properties hence it led to remove Na^+ far from root zone. ECe in root zone was decreased due to application of compost after harvesting of wheat and maize crops (6.75 and 6.15 dS m^{-1}), respectively, with reduction of 13.9% and 21.56% respectively. These findings agree with Sarwar et al. (2008), Lakhdar et al. (2009). Addel-Fattah (2012) and Mahdy (2011). Physical and chemical which may ultimately increase crop yield, so, use of compost is the need of time. Physical properties like bulk density, porosity void ratio, water permeability and hydraulic conductivity were significantly improved when Fym (10 tha^{-1}) was applied in combination with chemical amendments, resulting in enhanced rice and wheat yield in a sodic soil (Hussain et al. 2001).

Also, data showed that the in-root zone was decreased due to application of magnetite after harvesting of wheat and maize (7.12 and 6.43 dsm^{-1}), respectively, with Ece reduction of 9.18% and 17.98% respectively as compared with those before experiment (7.84 dS m^{-1}). The obtained results seem to agree with Hassan et al., (2005). Mahjob and Taher, (2005). Huang et al., (2008), Taha et al., (2011), Yusuf and Ogunlela (2015). Khalil et al, (2016)., Khater et al., (2015) and Abd El-Ghaffar- Rania, (2018), Abo batta (2015), Bayoumy et al. (2019).

The data cleared that application of Sulphurhad positive effect on Ece in root zone (0-60 cm depth) with reduction of 7.39% and 12.63% after harvesting of wheat and maize crop, respectively as compared with before experiment Zhao et al. (1999).

Finally, EC_e along profile was affected by different treatments according to the following descending order;gypsum >zeolite >compost >magnetite >Sulphur>control under irrigation treatment I_1 (irrigation at 40% depletion of available soil moisture and 10% as leaching requirement (LR) was applied for each irrigation treatment for the both growing seasons.

Soil alkalinity (SAR and ESP)

Data in Table 4 showed that the soil amendments effectively in decreased of sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) than before experiment instillation in the soil (0-60cm depth). The mean values of SAR and ESP% before experiment were 14.80 and 17.05%, respectively. The highest reduction of SAR and ESP values through the two growing seasons (after harvesting of wheat and maize crops) were recorded under gypsum application as compared with other soil amendments. SAR and ESP after wheat crop decreased 24.32 and 22.05% as compared with SAR and ESP before experiment, respectively. These results may be due to the role of gypsum in providing ca^{+2} cation to replace the exchangeable Na^{+} on the exchange positions as observed by Khuder et al., (2017); Amer and Hashem, 2018.

TABLE 4. Some soil chemical properties and relative change of wheat and maize crops after harvesting as affected by different irrigation treatments and soil amendments

Treatments	Wheat						Maize					
	ECe (dsm^{-1})	RC ±%	SARe	RC ±%	ESP (%)	RC ±%	ECe (dsm^{-1})	RC ±%	SARe	RC ±%	ESP (%)	RC ±%
Irrigation treatments												
I_1	5.83	25.64	12.78	13.65	14.96	12.26	4.89	37.63	11.71	20.88	13.80	19.06
I_2	6.12	21.94	13.10	11.49	15.30	10.26	5.35	31.76	12.24	17.30	14.38	15.66
I_3	6.75	13.90	13.75	7.09	15.98	6.28	6.26	20.15	13.25	10.47	15.46	9.33
Soil amendments												
Control	7.49	4.46	14.42	2.58	16.67	2.23	7.12	9.18	13.99	5.47	16.23	4.81
Gypsum	5.96	23.98	12.81	13.45	14.99	12.08	4.52	42.35	11.20	24.32	13.29	22.05
Sulphur	7.26	7.39	14.17	4.26	16.42	3.69	6.85	12.63	13.18	10.95	15.38	9.79
Zeolite	6.28	19.89	13.14	11.22	15.34	10.03	5.78	26.28	12.41	16.15	14.56	14.60
Compost	6.75	13.90	13.65	7.77	15.88	6.86	6.15	21.56	13.01	12.09	15.20	10.85
Magnetite	7.12	9.18	14.03	5.20	16.27	4.57	6.43	17.98	13.45	9.12	15.71	7.86

$I_{1:}$ Irrigation at 40% depletion of available soil moisture; **$I_{2:}$** Irrigation at 55% depletion of available soil moisture; **$I_{3:}$** Irrigation at 70% depletion of available soil moisture; **RC%:** Relative change (±%); **SAR:**sodium adsorption ratio; **ESP:** exchangeable sodium percentage

Irrigation parameters

Amount of seasonal water applied

Data presented in Table 5 clearly showed that the values of seasonal water applied for wheat and maize crops were affected by irrigation treatments in the two growing seasons. The highest mean values through the two growing seasons were recorded under irrigation treatment I_1 (irrigation at 40% depletion of available soil moisture) comparing with other irrigation treatments (I_2 and I_3) which exposed to water stress through growth stages during the two growing seasons and the values are 2630m^3 fed^{-1} (62.62 cm) and 3660m^3 fed^{-1}(87.14 cm) in the first and second growing seasons, respectively. On the other hand, the lowest values of seasonal water applied were recorded under irrigation treatment I_4 (irrigation at 70 % depletion of available soil moisture), the values are 2362m^3 fed^{-1} (56.24cm) and 3224m^3 fed^{-1} (76.76cm) in the first and second growing seasons, respectively. Generally, the values of seasonal water applied through the two growing seasons can be descended in order $I_1>I_2>I_3$. Increasing the values of seasonal water applied in the two growing seasons under irrigation treatment (I_1) comparing with other irrigation treatments which exposed to water stress through the two growing seasons (I_2 and I_3) might be due to increasing number of irrigations under irrigation treatment (I_1) in comparison with (I_2 and I_3). These results are harmony with those obtained by Ali et al. (2007), Mahamed et al., (2011), Beshara, (2012) and El-Agrodi, et al., (2016), Halli et al (2017).

Water consumptive use (WCU) (m^3 fed^{-1})

Data in Table 5 show that the mean values of water consumptive use were decreased with irrigation treatments I_2 and I_3. The highest mean value of WCU (1730 and 2276 m^3 fed^{-1}) was recorded with irrigation treatment I_1 during the two growing seasons, respectively. On the other hand, the lowest mean values (1557 and 2182 m^3 fed^{-1}) were recorded under irrigation treatment I_3 for the two growing seasons, respectively. Generally, the mean values of water consumptive use can be descended in order $I_1>I_2>I_3$ in the two growing seasons. The effect of irrigation treatments on water consumptive use might be attributed to the increase of water applied. So, the volume of water consumptive use was decreased as soil available water decreased. These results are in a great harmony with those obtained by El-Agrodi et al. (2016).

Water stored in the effective root zone (WS) (m^3 fed^{-1})

Data in Table 5 showed that the values of water stored in the effective root zone were affected by irrigation treatments. The highest mean values of WS (1856 and 2739 m^3 fed^{-1}) were recorded under irrigation treatment I_1 during the two growing seasons, the lowest overall mean values were recorded under irrigation treatment (I_3) and the values are (1626 and 2415 m^3 fed^{-1}) in the two growing seasons, respectively. Increasing the amount of water stored in the effective root zone under irrigation treatment (I_1) might be attributed to the increase in the number of irrigations hence, increasing the amount of water applied so, large amounts of water still stored in root zone over plants requirements. These findings These results agreed with El-Agrodi et al. (2016).

Water consumptive use efficiency (WCUE) and irrigation application efficiency (Ea)

Data presented in Table 5 revealed that the values of WCUE and Ea were affected by irrigation treatments. The highest percentage of WCUE (66.16 and 67.68%) was recorded under irrigation treatments I_2 and I_3during the two growing seasons. As shown in Table 5, the highest mean values were recorded under irrigation treatment (I_2) and the values are 72.63 and 78.24% comparing with other irrigation treatments I_1 and I_3, respectively. The lowest values of WCUE (65.78) and 62.19%) and the lowest values of Ea (70.57 and 75.84%) were obtained with irrigation treatment (I_1), respectively. These results agreed with EL-Agrodi et al. (2016).

Water productivity (wp, kg m^{-3}) and productivity of irrigation water (PIW, kg m^{-3})

Water productivity is generally defined as crop yield per cubic meter of water consumptive use. While productivity of irrigation water (PTW) is generally defined as crop yield per cubic meter of water applied. Data presented in Table 6 illustrated that the values of water productivity and productivity of irrigation water were high significant by irrigation treatments in both seasons. The highest values were obtained with I_2 treatment where the values of WP and PIW were found to be 3.650 and 2.442 kg m^{-3} for total wheat grain and straw yield in the first season. While in the second season, the corresponding values were found to be 5.821 and 3.819 kg m^{-3}. Data in Table 6 showed that the soil amendments treatments had high significant effect on water productivity and productivity of irrigation water in the two growing seasons.

TABLE 5. Effect of different irrigation treatments on some water parameters of wheat and maize plants.

Irrigation Treatments	Wheat				Maize			
	Applied water		Water saving		Applied water		Water saving	
	cm fed^{-1}	m^3 fed^{-1}	%	m^3 fed^{-1}	cm fed^{-1}	m^3 fed^{-1}	%	m^3 fed^{-1}
I_1	62.62	2630	-	-	87.14	3660	-	-
I_2	59.24	2488	5.4O	142	80.64	3387	7.46	273
I_3	56.24	2362	10.19	268	76.76	3224	11.91	436

Irrigation Treatments	Wheat				Maize			
	WCU (m^3 Fed^{-1})	SW (m^3 Fed^{-1})	WCUE (%)	Ea (%)	WCU (m^3 Fed^{-1})	SW (m^3 Fed^{-1})	WCUE (%)	Ea (%)
I_1	1730	1856	65.78	70.57	2276	2739	62.19	74.84
I_2	1646	1807	66.16	72.63	2206	2650	65.13	78.24
I_3	1557	1626	65.92	68.84	2182	2415	67.68	74.91

$I_{1:}$ Irrigation at 40% depletion of available soil moisture; **$I_{2:}$** Irrigation at 55% depletion of available soil moisture; **$I_{3:}$**Irrigation at 70% depletion of available soil moisture; **WCU:**Water Consumptive use; **WS:**Water Stored;**WCUE:**Water Consumptive Use Efficiency; **Ea:**irrigation application efficiency.

TABLE 6. Effect of different irrigation treatments and soil amendments on water productivity and irrigation water productivity of wheat and maize crops .

Treatments	Water productivity (WP kgm-3)				Irrigation water productivity			
	Wheat		Maize		Wheat		Maize	
	grain	straw	grain	stalk	grain	straw	grain	stalk
Irrigation treatments (I)								
I_1	1.509	1.647	1.114	3.971	0.993	1.083	0.693	2.725
I_2	1.659	1.991	1.202	4.619	1.121	1.321	0.773	3.046
I_3	1.598	1.658	1.107	3.802	1.051	1.092	0.749	2.592
F.Test	**	**	**	**	**	**	**	**
$LSD_{0.05}$	0.022	0.023	0.006	0.012	0.018	0.008	0.011	0.008
$LSD_{0.01}$	0.037	0.038	0.011	0.021	0.030	0.144	0.018	0.014
Soil amendments(SA)								
Control	1.426	1.437	0.988	3.564	0.942	0.948	0.642	2.416
Gypsum	1.610	1.824	1.176	4.205	1.062	1.204	0.744	2.842
Sulphur	1.485	1.615	1.054	3.869	0.979	1.063	0.685	2.611
Zeolite	1.619	1.928	1.229	4.405	1.112	1.271	0.799	2.975
Compost	1.758	2.096	1.293	4.775	1.173	1.379	0.841	3.206
Magnetite	1.607	1.690	1.103	3.969	1.059	1.117	0.717	2.676
F. Test	**	**	**		**	**	**	
$LSD_{0.05}$	0.017	0.021	0.006	0.014	0.011	0.01	0.015	0.009
$LSD_{0.01}$	0.022	0.029	0.008	0.02	0.015	0.015	0.020	0.013
Interaction								
I X SA	**	*	**	**	**	*	**	**

$I_{1:}$ Irrigation at 40% depletion of available soil moisture; **$I_{2:}$** Irrigation at 55% depletion of available soil moisture; **$I_{3:}$**Irrigation at 70% depletion of available soil moisture;

The highest values were obtained with application of compost treatment where the values of WP and PIW were found to be 3.854 and 2.552 kg m^{-3} for total wheat grain and straw yield in the first season. While in the second season, the corresponding values were found to be 6.068 and 4.047 kg m^{-3}. Data presented in Table 6 indicated that the WP and PIW showed high significant Interaction between Irrigation treatments and soil amendments treatments. The highest values were obtained with compost, zeolite and gypsum treatments under irrigation treatment I_2 (irrigation at 55% depletion of available soil moisture).

Yield and some yield attributes

Yield of wheat and maize

Data in Table 7 revealed that the different irrigation treatments had high significant effect on grain and straw yield in the first and second seasons respectively. It is clear that the maximum values of grain yield were produced from irrigation treatment I_2 (Irrigation at 55% depletion of available soil moisture). While the minimum values were obtained under irrigation treatment I_3 (Irrigation at 70% depletion of available soil moisture). Data showed that grain and straw yield of wheat and maize were highly significantly increased and recorded the highest values due to application of soil amendments treatments. As a general, the application of compost, gypsum and zeolite under irrigation treatment I_2 (Irrigation at 55% depletion of available soil moisture) of salt affected soils and achieved the highest productivity. Finally, the soil productivity as affected by different order: compost > zeolite > gypsum > magnetite >Sulphur> control (check treatment).

TABLE 7. Impact of different irrigation treatments and soil amendments on productivity of wheat and maize crops.

Treatments	Wheat			Maize		
	Grain yield (ton fed^{-1})	Straw yield (ton fed^{-1})	1000 grains weight (g)	Grain yield (ton fed^{-1})	Stalk yield (ton fed^{-1})	100-grian weight (g)
Irrigation treatments (I)						
I_1	2.610	2.840	49.59	2.535	9.157	47.76
I_2	2.787	3.276	50.62	3.653	10.317	49.18
I_3	2.490	2.584	48.55	2.417	8.361	46.86
F.Test	**	**	**	**	**	**
$LSD_{0.05}$	0.031	0.022	0.36	0.015	0.027	0.282
$LSD_{0.01}$	0.051	0.036	0.61	0.025	0.046	0.468
Soil amendments (SA)						
Control	2.348	2.364	46.23	2.195	8.040	45.10
Gypsum	2.647	2.986	50.23	2.613	9.457	48.49
Sulphur	2.440	2.657	49.00	2.346	8.690	46.44
Zeolite	2.780	3.176	50.85	2.730	9.900	49.56
Compost	2.921	3.434	51.48	2.873	10.670	50.47
Magnetite	2.639	2.783	49.73	2.450	8.913	47.53
F.Test	**	**	**	**	**	**
$LSD_{0.05}$	0.030	0.024	0.37	0.014	0.032	0.194
$LSD_{0.01}$	0.039	0.032	0.51	0.019	0.044	0.261
Interaction						
IxSA	**	**	**	**	**	**

$I_{1:}$ Irrigation at 40% depletion of available soil moisture; **$I_{2:}$** Irrigation at 55% depletion of available soil moisture; **$I_{3:}$**Irrigation at 70% depletion of available soil moisture;

Economical evaluation

Data in Table 8 showed the costs of agriculture materials and price yield of wheat and maize according to the local market. Also, data in Fig. 1 and 2 showed that the gross and net incomes were obviously increased by compost application under irrigation treatment I_2 (Irrigation at 55% depletion of available soil moisture). This achieved the highest values of gross and net incomes of wheat (10573.45 and 5973.45 LE fed-1, respectively) and maize (11130.12 and 6930.12 LE fed-1, respectively). Concerning the economic efficiency, the highest values (2.30 and 2.75) for wheat and maize were recorded due to the combined between compost and irrigation treatment I_2 for wheat and combined between zeolite application and irrigation treatment I_2, respectively. Concerning the economic water efficiency, the highest values (0.77 and 0.88) for wheat and maize were recorded due to the combined between control and irrigation treatment I_3 (Irrigation at 70% depletion of available soil moisture). While, the lowest values (0.42 and 0.49) for wheat and maize were recorded due to the combined between compost application under irrigation treatment I_2 (irrigation at 55% depletion of available soil moisture).

TABLE 8. Costs of agriculture treatment materials and price yield of wheat and maize

Item	Variable cost (LE Fed $^{-1}$)					Fixed cost (LE Fed $^{-1}$)	Total cost (LE Fed $^{-1}$)	Price (LE Mg $^{-1}$)	
	Gypsum	Sulphur	Zeolite	Compost	Magnetite			Grain	Straw
Wheat	240	50	100	500	100	4100	5090	2700	560
Maize	240	50	100	500	100	3700	4690	3000	170

Notices:

1. Total cost (LE Fed. $^{-1}$) =fixed cost (LE Fed. $^{-1}$) + variable cost (LE Fed. $^{-1}$)
2. Gross income (LE Fed. $^{-1}$) = grain yield x price + straw yield x price
3. Net income = gross income (LE Fed $^{-1}$) - total costs (LE fed $^{-1}$)
4. Economic efficiency (Eco. Eff.) = Gross income (LE Fed $^{-1}$) /total cost (LE Fed $^{-1}$)

*Total cost for gypsum (LEFed. $^{-1}$) for barely and rice

** Total cost for compost (LEFed. $^{-1}$) forwheat and maize

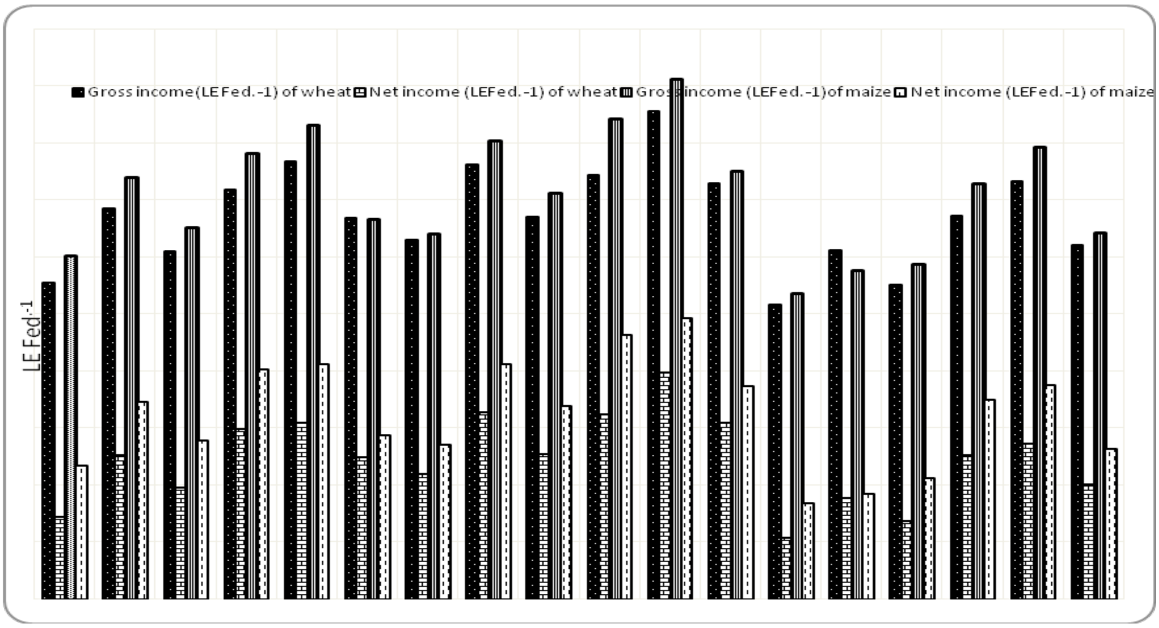

Fig. 1. Gross income and net income of wheat and maize as affected by different treatments.

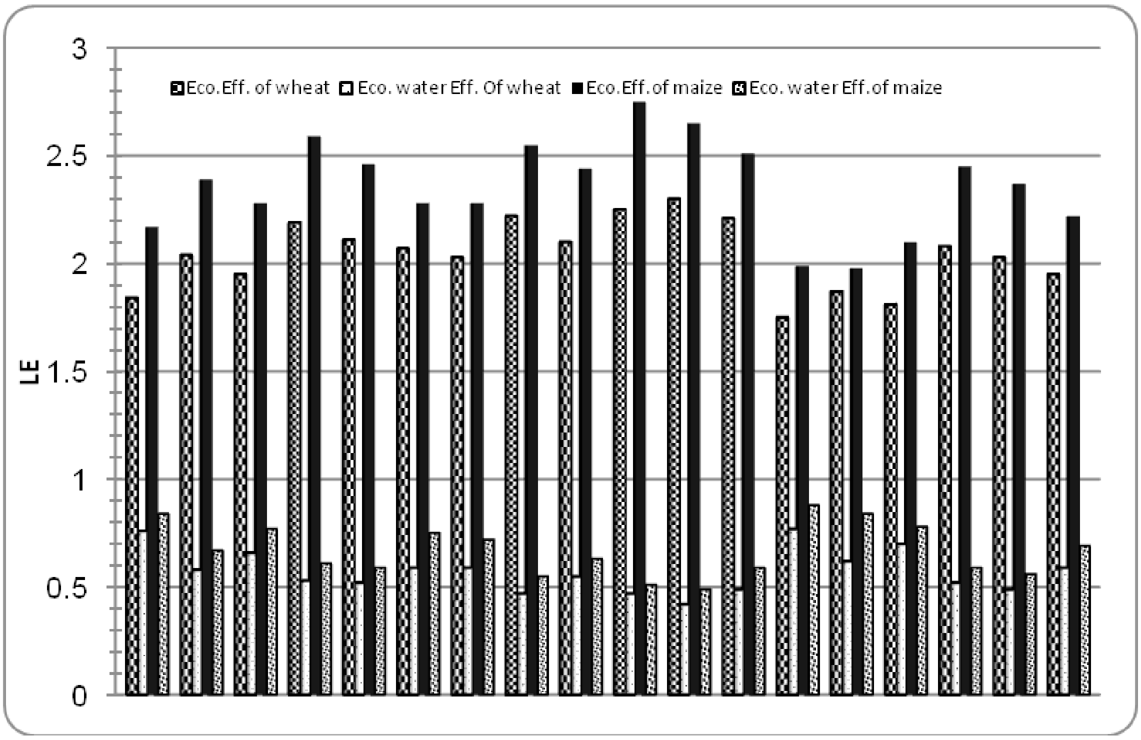

Fig. 2. Economic efficiency and economic water efficiency of wheat and maize as affected by different treatments.

Conclusion

It could be concluded that application of soil amendments; gypsum, sulphur, zeolite, compost and magnetite to improved soil properties, maximized economic water efficiency and productivity of wheat and maize plants.

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