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Effect of Gypsum, K-Humate and Plant Growth Promoting Bacteria on Improvement of Soil Properties and Productivity of Wheat and Maize Irrigated by Saline Water

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ABSTRACT

Because of water shortage in North Nile Delta, Egypt, some farmers have to irrigate their crops by saline water. So, soils and/or plants are preferred to be treated by some amendments to alleviate the hazardous effects of salt stress. Two field experiments were conducted at Sakha Agric. Res. Station Farm, Kafr Elsheikh Gov., Egypt, to study the effect of gypsum (50, 75 and 100% of gypsum requirement, 8.2 t ha^{-1}), K-humate (5 and 10 kg ha^{-1}) and inoculation with plant growth-promoting-rhizobacteria (PGPR), (10^8-10^9 colony, ml^{-1}) on soil properties and productivity of wheat (2018/19) and maize (2019) irrigated by saline water (0.7 and 2.43 dSm^{-1}). The results revealed that plant height, grain filling, grain and straw yields of wheat and maize were negatively affected by irrigation water salinity. Also, irrigation water salinity clearly affected soil ECe and ESP, while it slightly affected soil bulk density and total porosity. Also, soil ECe, ESP, bulk density and total porosity were slightly affected by application of gypsum, K-humate and PGPR. The biomass yield, plant height and grain filling in both crops were positively affected by gypsum application, whereas it alleviated the adverse effects of salinity on crop growth. Also, K-humate with PGPR positively affected the crop yield and its attributes. The bio amendments alleviated the harmful effects of salinity stress on both crops. Finally, 100% gypsum combined with higher rate of K-humate and PGPR treatments was more effective treatment on plant growth and alleviated the harmful effects of salinity stress on plant growth.

Keywords: Wheat, maize, salinity, gypsum, PGPR

INTRODUCTION

The a biotic stress such as salinity is the main threat to the plant production all over the world, whereas it is one of the most serious factors limiting the productivity of agricultural crops (Munns and Tester 2008). The yield of majority of plants start declining even at relatively low salinity (ECe >1 dS/m) in soil (Chinnusamy *et al.*, 2005) through restricting the uptake of water and nutrients (Tester and Davenport 2003), the root function, growth rates and yields (Munns 2002) due to osmotic pressures affects. Salinity occurred from irrigation is widely responsible for increasing soil salts to a level that impairs plant growth (Manchanda and Garg 2008), such as maize (Mahajan and Tuteja 2005 and Queiroz *et al.*, 2012). The most common salt is NaCl (Greenberg *et al.*, 2010), leading to excessive uptake of Na^+ and Cl^- and reduces uptake of K^+ and Ca^{2+} (Tester and Davenport 2003).

Overcoming salt stress in saline soil can be achieved by leaching or adding gypsum (Egamberdieva *et al.*, 2019) to improve soil hydro-physical, chemical and biological properties (Morsy *et al.*, 1982) such as bulk density (Massoud 2006) and it remediates saline soils, being low cost, effective and simple (Sharma and Minhas 2005; Makoi and Verplancke 2010). Recently, gypsum ($CaSO_4.2H_2O$) is being used to alleviate water quality problems and improve crop yield (Fisher, 2011). So, gypsum improves irrigation water quality and decreases the hazardous effects of high EC and SAR (Ghafoor *et al.*, 2001). Elsaka *et al.*, (2018) found that soluble Ca and chitosan positively affected plant height, 100-grain weight, grain and straw yields of maize, slightly decreased soil EC, SAR and ESP values and alleviated the adverse effects of salinity stress. Bayoumy *et al.*, (2019) reported that gypsum, compost and biochar increased wheat grain yield and decreased soil ECe. Cha-um *et al.*, (2011) observed that Na^+ in soil cultivated by rice and treated with gypsum and farm yard manure (FYM) was lower than that in untreated soil, while the K^+ level was enriched, so application of gypsum and FYM to saline soil reduces salts defects on plant. So, gypsum is a source of Ca^{2+} for ameliorating Na^+ saturated water/soils (Amezketa *et al.*, 2005) and it ameliorates productivity of saline soil due to overcoming salt stress (Makoi and Verplancke 2010). Hassan (2016) found that drip fertigation with 125 % of recommended K with humic acid plus gypsum gave high growth of plants irrigated by saline water, since Ca according to Aranda-Peres *et al.*, (2009) is needed for cell wall strengthening and provides protection against biotic and abiotic stresses.

Moreover, organic substances can be used as soil amendments, possibly due to that the nutrients are slowly released from organic compost and not directly absorb by plants (Adugna 2016). K-humate increases product quality and plant tolerance to drought stress, salinity, heat, cold, disease and pests (Khordhidi *et al.*, 2009). Humic substances can be used as alternate sources of organic

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matter to improve soil physico-chemical properties as well as crop growth and yield (Ohta *et al*., 2004; Johan, 2008). The direct and indirect effects of humic acid to alleviate the inhibitory effect of soil salinity are improving the physical and chemical properties of soil (Hemida *et al.,* 2017). Also, the humic substances stabilize aggregates for a long term in which they are mainly involved in the micro-aggregate formation (Chaney and Swift 1986). Awwad *et al.,* (2015) concluded that 15 kg K-humate fed^{-1} with full irrigation improved maize yield and its attributes and soil properties. Also, Habashy and Ewees (2011) reported that gypsum with *arbuscular mycorrhizal* fungi (AMF) and K-fulvate in moderately saline soils improves its characters; nutrients availability and gypsum efficiency and positively reflected on the yield. Increasing of K-humate applied significantly increased availability of some macro and micronutrients contents in soil such as N, P, K, Fe, Mn and Zn Abd Elghany *et al.,* (2019).

The major source of salinity in arid and semi-arid regions is salt-rich irrigation water and treating the plants by bacteria and fungi (Plaut *et al.,* 2013) or inoculating seeds and seedlings by plant growth promoting rhizobacteria (PGPR) like *Staphylococcus kloosii* and *Kocuria erythromyxa* (Yildrim *et al.,* 2008 and Amirjani 2010) are suggested for alleviating salinity stress (Shrivastava and Kumar 2014). PGPRs indirectly enhance stress tolerance by increase the activity of some antioxidant enzymes during the intense photosynthesis (Stefan *et al.,* 2013) and they provide excellent models for understanding the stress tolerance, adaptation and response mechanisms that can be subsequently engineered into crop plants to cope with climate change induced stresses (Grover *et al.,* 2011). Paul and Lade (2014) reported that use of PGPR can alleviate salinity stresses on plants through the following benefits or strategy: (1) better root and shoot growth, nutrient uptake, hydration and chlorophyll contents, and resistance to diseases; (2) stress tolerance can be explained by nutrient mobilization and bio control of phytopathogens in soil and by production of phytohormones and 1-aminocyclopropane-1-carboxylate deaminase; (3) favour the circulation of plant nutrients in soil; (4) favour osmolytes accumulation in plants; (5) favour salinity tolerance by higher K^+/Na^+; and (6) degrade reactive oxygen species generated upon salt shock by synthesis of antioxidative enzymes. So, Rojas-Tapias *et al.,* (2012) found that N_2-fixing PGPB alleviated saline stress in maize through increasing K^+/Na^+ ratio. The alleviating of negative effects of abiotic stress on plant was achieved in faba bean treated by *Pseudomonas fluorescens* (Metwali1 *et al.,* 2015), tomato treated by *Azotobacter chroococcum* strains of 67B and 76A (Viscardi et al., 2016), pepper treated by PGPR (Hahm *et al.,* 2017), wheat treated by *Triticum aestivum* bacterial strains (Orhan 2016) or by halo-tolerant bacteria isolated from saline environments (Ramadoss *et al.,* 2013). Also, Kotuby-Amazher *et al.,* (2000) exposed that microorganisms can lessen salt stress in maize and wheat by 50%. Under drought stress conditions, inoculating plants by *Azospirillum lipoferum* increased accumulation of free amino acids and soluble sugars to protect themselves from stress (Bano *et al.,* 2013). Also, inoculating plants by *Azospirillum* increased proline content (Kandowangko *et al.,* 2009), which maintains the cell water status to cope plants with salinity stress. Also, Evelin *et al.,* (2019) reported that the use of AMF is an efficient approach for bio-amelioration of salinity stress through biochemical and physiological mechanisms which provide more plant-tolerant to salinity, improve water use efficiency and osmo-protection for plant. Also, PGPR under salt conditions minimizes the intensity of 1-aminocyclopropane-1-carboxylate (ACC) which justify the toxic effects of salt stress on wheat (Arshadullah *et al.,* 2017). In addition, AMF decreases plant yield losses in saline soils (Sannazzaro *et al.,* 2006), possibly due to increased uptake of nutrients with low mobility, such as P, Fe, Cu and Zn (Al-Karaki 2000) and decrease Na^+ uptake (Al-Karaki 2006). Therefore, this study aims to evaluate effects of gypsum, K-humate and plant growth promoting rhizobacteria (PGPR) on improving some soil properties and productivity of wheat and maize irrigated by poor quality water.

MATERIALS AND METHODS

Two field experiments were conducted at Sakha Agric. Res. Station Farm, Kafr Elsheikh Gov., Egypt, to study the effect of gypsum, K-humate and inoculation with plant growth promoting rhizobacteria (PGPR), as well as their interactions on some soil properties and productivity of wheat (2018/19) and maize (2019) crops under salinity of irrigation water.

The soil in the experimental site is clayey salt affected soil. Soil samples were taken before experiment and after harvesting from each treatment. Electrical conductivity, ECe (dSm^{-1}), soluble cations and anions were determined in saturated soil paste extract, and cation exchange capacity and exchangeable cations were determined according to Page (1982). Particle size distribution of soil was determined using pipette method according to Gee and Bauder (1986). Soil bulk density (BD) was determined before experiment and at the end of the experiment for each treatment using core method according to Klute (1986). Total porosity (TP) was estimated from soil bulk density and soil particle density values (Black, 1965) using the equation:

$$\mathbf{TP = 1 - (\rho b / \rho s) \times 100}$$

Where:

ρb: soil bulk density and ρs: soil particle density (2.65 g cm^{-3}).

Field capacity and permanent wilting point were calculated from soil moisture tension curve (Black, 1965). Some physical and chemical properties of the experimental soil are shown in Table 1.

Table 1. Some physical and chemical properties of surface soil before experiment.

Soil characteristics	Value	Soil characteristics	Value
Particle size distribution (%)		ECe (dS/m)	8.46
Sand	18.3	Soluble cations (meq/L)	
Silt	28.6	Na^+	57.4
Clay	53.1	K^+	0.7
$CaCO_3$ (%)	3.1	Ca^{2+}	18.3
O.M (%)	0.9	Mg^{2+}	10.1
Soil texture	Clayey	Soluble anions (meq/L)	0
Bulk density (g/cm^3)	1.38	CO_3^{-2}	0
Total porosity (%)	47.9	HCO_3^-	5.5
CEC (meq/100 g soil)	37.9	Cl^-	52
SP	72.9	$SO4^{-2}$	29
FC %	36.9	SAR	15.2
ESP	17.6	pH	8.1

The experiment was designed as split-split plot design with three replicates during the both seasons. Two salinity levels of irrigated water, ie. normal, S_1 (0.7 dSm^{-1}), and saline, S_2 (2.43 dSm^{-1}) formed the main plot units. The sub-plots treatments were as gypsum at the rates of 4.1, 6.15 and 8.2 ton ha^{-1}, equivalent 50, 75 and 100% GR, respectively, while, the sub-sub plot units were as Ck: control, 5 kg K-humate ha^{-1} (H_1), 10 kg K-humate ha^{-1} (H_2), growth promoting (PGPR), H_1 + PGPR and H_2+ PGPR. K-humate and irrigation water properties are shown in Tables 2. Gypsum requirement was calculated based on the values of soil cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) to reduce the initial soil ESP in the surface layer to the required level (10). It was calculated according to FAO and IIASA (2000) as follow:

$$GR = (ESP_i - ESP_f)/100 \text{ x } CEC \text{ x } 1.72$$

Where GR: gypsum requirement (Mg fed^{-1}), ESP_i: initial soil ESP, ESP_f: the required soil ESP and CEC: cation exchange capacity (meq/100 g).

Table 2. Some chemical analysis of K-humate and irrigation water

K-humate							
EC (dSm^{-1})	**pH**	**OM (%)**	**Total C (%)**	**Total N (%)**	**C/N ratio**	**Total P (%)**	**Total K(%)**
6.88	8.94	59.5	34.2	2.15	15.9	0.36	7.75

Irrigation water										
Salinity level	EC_w dSm^{-1}	Cations (meq/L)				Anions (meq/L)				SAR
		Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{-2}	HCO_3^-	Cl^-	SO_4^{-2}	
Normal (S_1)	0.7	4.8	0.1	1.5	1.3	0	1.5	4.3	1.9	4.1
Saline (S_2)	2.43	16.5	0.2	5.3	4.5	0	2.5	14.9	9.1	7.5

In the 1st season, wheat (*Triticum aestivum* L., CV. *Gemmiza 11*) was sown at rate of 170 g $plot^{-1}$ (3x4 m), while maize (*Zea mays* L., *Hybrid Cross 10*) was sown in five ridges (4 m in length 60 cm apart) at the rate of 2 grain per hole with 20 cm space. The seeds of both crops were obtained from Field Crops Research Institute, Agricultural Research Centre, Giza, Egypt. Gypsum was thoroughly mixed with the surface soil layer (0-30 cm) before cultivation, where the application of K-humate was blended with water and was applied before sowing and with the 1st irrigation of both crops. Also, PGPR *Azosprillium lipoferum* SARS12 and *Enterobacter cloacae* KX034162 was applied to both crops as a mixture (10^8-10^9 colony-forming units, ml^{-1}) with 1:1 ratio, which mixed with the peat carrier then kept at room temperature and mixed with seeds before sowing using a sticking material.

Grain and straw yield, plant height and grain filling were recorded for both crops and subjected to the statistical analysis according to Gomez and Gomez (1984) and means of the treatments were compared by the least significant difference (LSD) at 5 % level according to Waller and Duncan (1969).

RESULTS AND DISCUSSION

A. Soil characteristics as affected by different treatments:

Chemical characteristics: Data related to the post-harvest electric conductivity (ECe) and exchangeable sodium percentage (ESP) are given in Table (3) and Fig (1).

Table 3. Mean effects of gypsum, K-humate and PGPR on soil ECe and ESP under salinity conditions

	Treatments	**ECe (dS/m)**			**+%**	**ESP**			**+%**
		S_1	**S_2**	**Mean**	**S_1 vs. S_2**	**S_1**	**S_2**	**Mean**	**S_1 vs. S_2**
Amendments	Ck	6.02	7.16	6.59	18.9	13.7	15.9	14.8	15.8
	H_1	5.79	6.83	6.31	18.0	13.2	15.2	14.2	15.7
	H_2	5.66	6.64	6.15	17.3	12.9	14.7	13.8	14.5
	PGPR	6.03	7.13	6.58	18.3	13.7	15.9	14.8	15.8
	H_1+PGPR	5.74	6.8	6.27	18.5	13.1	15.2	14.1	16.1
	H_2+PGPR	5.60	6.59	6.10	17.7	12.8	14.6	13.7	14.6
Gypsum	50% Gr	6.19	7.24	6.72	17.0	13.7	15.7	14.7	14.5
	75% Gr	5.71	6.77	6.24	18.4	13.2	15.2	14.2	15.7
	100% Gr	5.51	6.57	6.04	19.1	12.8	14.8	13.8	16.2
	Main-S	5.81	6.86	-	18.1	13.2	15.3	-	15.4

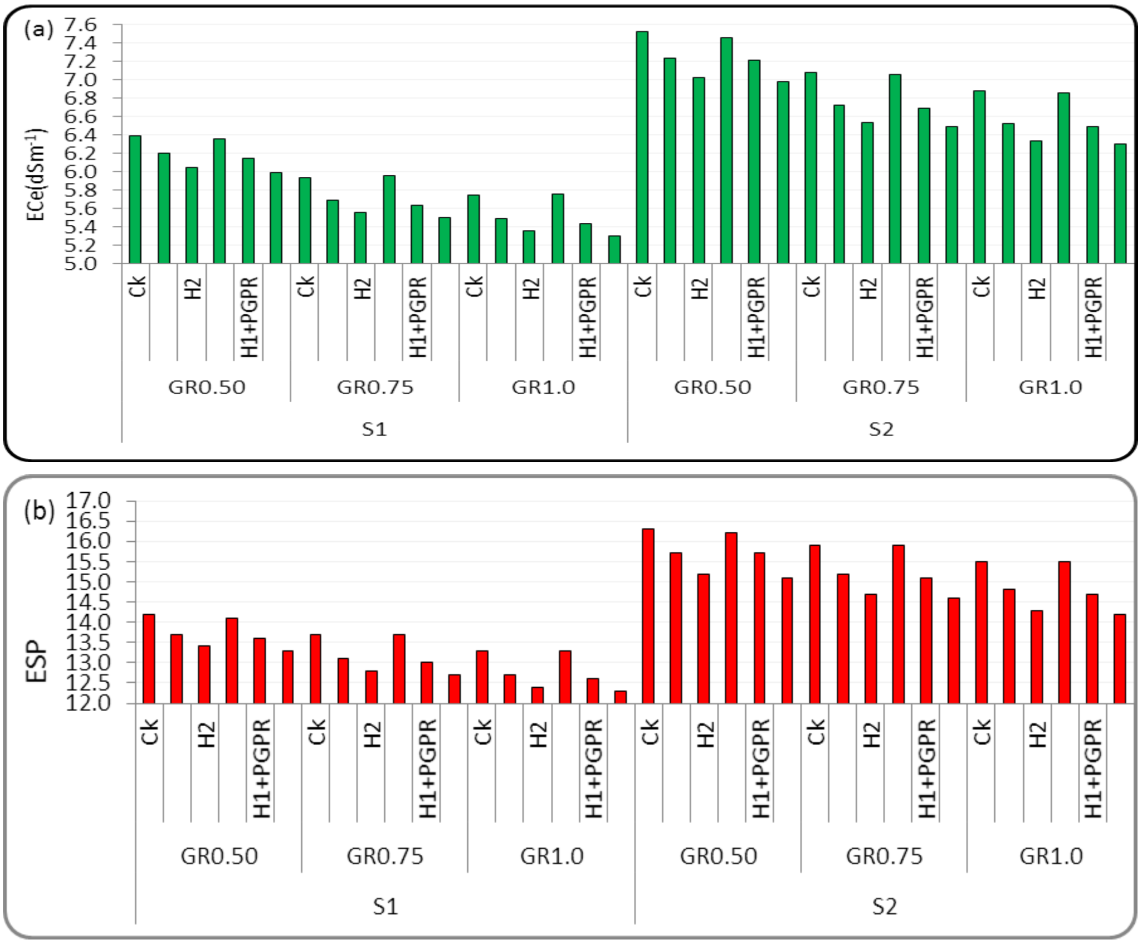
***Ck: Control, GR: gypsum requirement, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha and PGPR: plant growth promoting rhizobacteria**

Post-harvest soil ECe: Soil ECe values in surface layer at the end of the 2nd season are clearly affected by irrigation water salinity, whereas it increased by about 18.1% with saline water (S_2) over that irrigated by the normal water (S_1). These results may be in somewhat related to that salinity occurred from irrigation water is mainly responsible for increasing the soluble salts in soil profile (Manchanda and Garg, 2008 and Plaut *et al.,* 2013).

Soil ECe was slightly affected by gypsum application rate and it increased from 6.04 dS/m with application 100% of gypsum requirement (GR) to 6.72 ds/m due to application of 50% GR (+0.7 dS/m). Also, the influence of the soil amendments on ECe values are relatively low since the lowest value (6.10 dS/m) was recorded with H_2+PGPR treated soil, while the highest value was detected in untreated soil (6.59 dS/m).

Post-harvest soil ESP: ESP is moderately affected by salinity of irrigation water and soil amendments at the end of the 2nd season. The ESP values in soil irrigated by saline water were increased by about 15.4% over that irrigated by the normal water. These results may be due to that saline water provides soil solution by Na ions which lead to increase soil ESP values. Moreover, ESP value slightly affected by gypsum application rate and consequently, there were slight differences in ESP values with different gypsum rates, since its values with 100, 75 and 50% GR were 14.7, 14.2 and 13.8, respectively. This trend may be attributed to that gypsum as a source of Ca^{++} improves soil chemical properties (Morsy *et al.*, 1982).

On the other hand, soil ESP was slightly affected by application of soil amendments. The maximum ESP value (14.8) was recorded with the control or in PGPR treated soil, while the minimum value (13.7) was recorded in H_2+PGPR treated soil. Generally, the beneficial effect of the soil amendments, especially those included PGPR may be related to that they lead to higher K/Na ratio in plant and soil and consequently decreased ESP value (Paul and Lade, 2014).



***Ck: Control, GR: gypsum requirement, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha and PGPR: plant growth promoting rhizobacteria**

Fig.1. Effect of salinity, gypsum, K-humate and PGPR on a-soil ECe and b-ESP

Physical characteristic

Soil bulk density (BD) and total porosity (TP): The results of soil BD and TP with different treatments are illustrated in Table (4) and Fig (2). Both parameters are slightly affected by different treatments approximately in the same rate but in contrary trends. The post-harvest soil BD and TP are slightly affected by salinity of irrigation water. In soil irrigated by saline water, BD value was increased by 3.27%, while TP value was decreased by 3.17% compared to that with normal irrigation water. This trend may attribute to that salinity inhibits the growth of plant and microorganism's in soil, which led to decrease in its organic substances content, increase soil Bd and consequently decrease its TP.

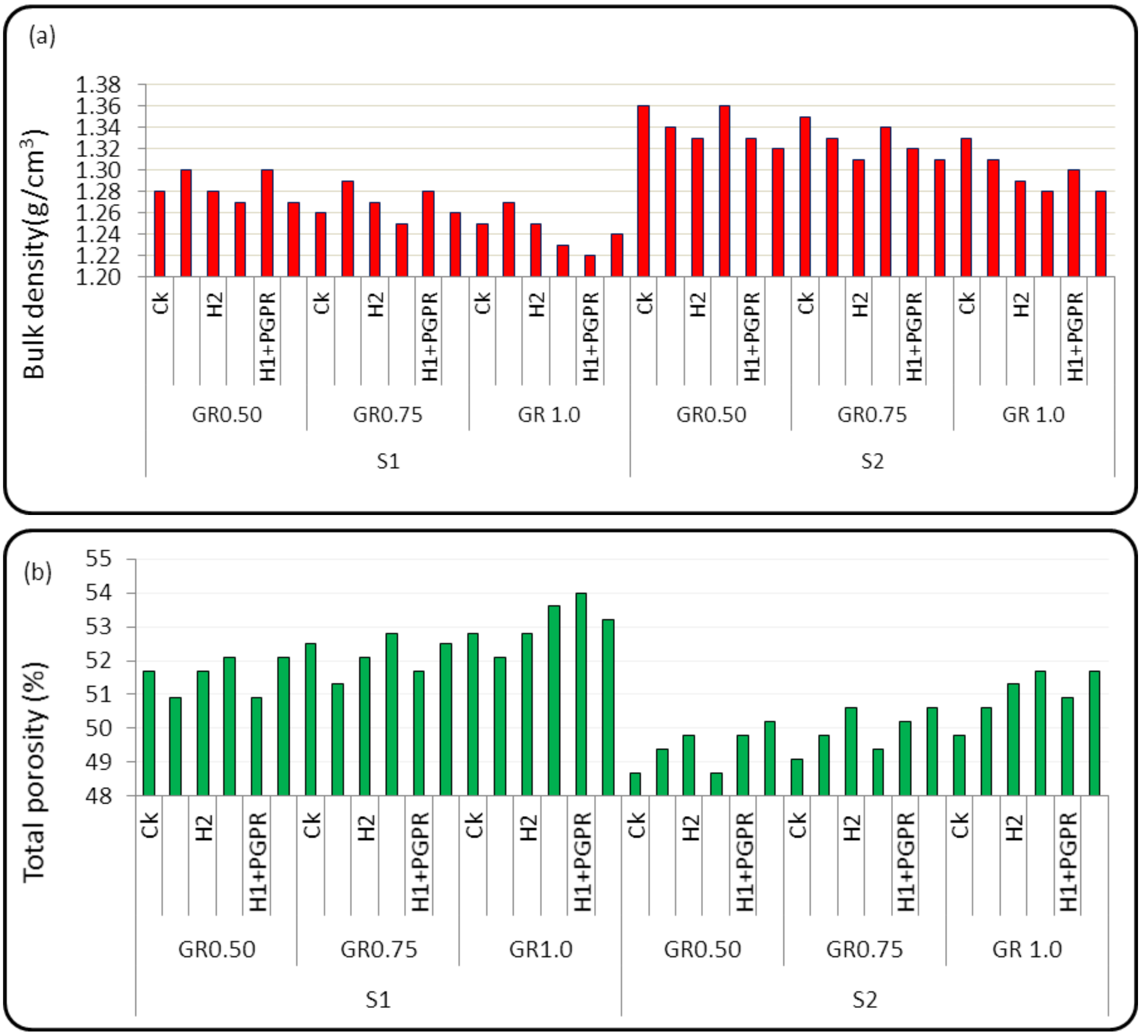
Table 4. Mean effects of gypsum, K-humate and PGPR on soil bulk density and total porosity under salinity conditions.

Treatments		Bulk density (g/cm^3)			+%	Total porosity (TP %)			- %
		S_1	S_2	Mean	S_1 vs. S_2	S_1	S_2	Mean	S_1 vs. S_2
Amendments	Ck	1.30	1.35	1.33	3.22	50.82	49.18	50.00	3.22
	H_1	1.28	1.33	1.31	3.27	51.57	49.94	50.75	3.17
	H_2	1.27	1.31	1.29	2.80	51.95	50.57	51.26	2.66
	PGPR	1.29	1.34	1.32	3.73	51.32	49.43	50.38	3.68
	H_1+PGPR	1.27	1.32	1.30	3.29	51.95	50.31	51.13	3.15
	H_2+PGPR	1.26	1.31	1.29	3.32	52.33	50.69	51.51	3.13
Gypsum	50% Gr	1.30	1.34	1.32	3.23	51.07	49.43	50.25	3.20
	75% Gr	1.28	1.33	1.30	3.64	51.76	49.94	50.85	3.52
	100% Gr	1.27	1.31	1.29	2.93	52.14	50.69	51.42	2.77
Main-S		1.28	1.32	-	3.27	51.66	50.02	-	3.17

***Ck: Control, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha and PGPR: plant growth promoting rhizobacteria**

Also, soil BD and TP values were slightly affected by increasing of gypsum application rate. The BD values were 1.32, 1.30 and 1.29 g/cm^3, while TP values were 50.25, 51.85 and 51.42% in soil treated by 50, 75 or 100% GR, respectively. This may be related to that gypsum increases soil porosity due to decreases its BD (Ahmed, (2009); Habashy and Ewees, 2011), which decreases with increasing gypsum application rate (Massoud, 2006).

Moreover, both BD and TP parameters were slightly affected by application of soil amendments. The minimum BD value (1.29 g/cm^3) and maximum TP value (51.51%) were observed in H_2+PGPR treated soil, while the maximum BD (1.33 g/cm^3) and minimum TP (50.00%) were recorded in untreated soil. These results may be related to that humic substances stabilize soil aggregates since they are mainly involved in the micro-aggregate formation (Chaney and Swift, 1986), the application of organic fertilizer such as compost improves soil physical properties such as total porosity (Amer *et al.,* 2019), or gypsum combined with other amendments improve soil hydro-physical properties (Morsy *et al.*, 1982).



***Ck: Control, GR: gypsum requirement, H_1:5 kg K-humate/ha, H_2:10 kg K-humate/ha and PGPR: plant growth promoting rhizobacteria**

Fig. 2. Effect of salinity, gypsum, K-humate and PGPR on a-bulk density and b-total porosity

B. Effect of treatments on plant parameters:

Plant height and **grain filling:** The effects of salinity levels and soil amendments on plant height and grain filling for wheat and maize are illustrated in Tables (5-7) and Figs (3).

Plant height: Irrigation water salinity negatively affected plant heights in both crops, whereas the decreases in heights of wheat and maize irrigated by saline water were about 15.8 and 10.8%, respectively. Concerning the effect of gypsum, the plant height of wheat was significantly affected and increased by 6.1 and 12.1% with gypsum rates of 75 and 100% GR, respectively compared with 50% GR. The increases of plant height in maize were 20.0 and 16.8 with 75 and 100% GR, respectively over that with 50% GR. These results are similar to those obtained by Ahmed (2009) who observed that gypsum as a source of Ca^{++} and S, improved plant height.

Also, soil amendments significantly affected plant height in both crops. The tallest plant heights for both crops were observed in H_2+PGPR treated plants (100.8 and 222.8 cm, respectively) while the lowest heights were recorded with the untreated plants (74.2 and 138.4 cm, respectively). The increases in plant height over the control were 8.9, 17.9, 17.9, 27.0 and 35.8% in wheat, and 27.7, 43.1, 34.7, 48.9 and 61.0% in maize treated by H_1, H_2, PGPR, H_1+PGPR and H_2+PGPR, respectively over that in untreated plants.

In addition, the soil amendments partially overcome the adverse effects of salinity stress on crop growth, whereas the height deceases of the amended plants irrigated by saline water were lower than that with untreated plants. So, the decreases in wheat heights with saline water were 18.4, 17.0, 15.8, 15.8, 14.8 and 13.8% and in maize they were 21.5, 11.3, 9.9, 11.0, 7.3 and 7.2% with CK, H_1, H_2, PGPR, H_1+PGPR or H_2+PGPR treated plants, respectively.

Table 5. Plant height, GW and yield of wheat and maize as affected by salinity, gypsum, K-humate and PGPR

Treatment	Wheat				Maize			
Salinity	P. height (cm)	1000-G (g)	Straw, ton/ha	Grain, ton/ha	P. height (cm)	100-G (gm)	Grain, ton/ha	Straw, ton/ha
S_1	95.0	47.3	10.28	3.51	198.8	45.8	7.73	22.68
S_2	80.0	38.3	7.69	2.63	177.3	40.4	6.75	19.80
F_{test}	**	**	**	**	**	**	**	**
Gypsum								
$GR_{0.50}$	82.5c	40.0 c	7.94c	2.71c	167.5c	39.6c	6.20c	18.18c
$GR_{0.75}$	87.5b	41.8 b	8.98 b	3.07b	201.0b	43.7b	7.39b	21.69b
GR_{100}	92.5a	46.7 a	10.03a	3.42a	195.7a	46.0a	8.13a	23.87a
F_{test}	**	**	***	**	**	**	**	**
Soil amend.								
Ck	74.2e	30.0 f	5.98 f	2.04e	138.4f	36.9f	4.49f	13.17 f
H_1	80.8d	38.9 e	8.22 e	2.81d	176.7e	39.5e	6.95e	20.39 e
H_2	87.5c	46.0 c	9.71 c	3.31b	198.1c	44.3c	7.78c	22.84 c
PGPR	87.5c	42.7 d	9.01 d	3.08c	186.4d	41.6 d	7.32d	21.46 d
H_1+PGPR	94.2b	47.2 b	9.96 b	3.40b	206.1b	46.2b	8.12b	23.82 b
H_2+PGPR	100.8a	52.2 a	11.03a	3.76a	222.8a	50.1a	8.78a	25.77 a
F_{test}	**	**	**	**	**	**	**	**
S*GR	ns	**	*	*	*	**	**	*
S*Bio	ns	**	*	*	*	**	**	*
GR*Bio	ns	**	*	*	*	**	**	*
S*Gr*Bio	ns	*	*	*	*	*	**	*

***Ck: Control, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha, PGPR: plant growth promoting rhizobacteria, Gr: gypsum requirement, S: salinity.**
***Means followed by the same letter are not significantly different at 5 % level**

Table 6. Mean effects of gypsum, K-humate and PGPR on plant height (cm) under salinity conditions

	Treatment	Wheat S_1	Wheat S_2	Wheat Mean	+% vs. CK	- % S_1 vs S_2	Maize S_1	Maize S_2	Maize Mean	+% vs. CK	- % S_1 vs S_2
Amendments	Ck	81.7	66.7	74.2	0.0	18.4	155.1	121.7	138.4	0.0	21.5
	H_1	88.3	73.3	80.8	8.9	17.0	187.2	166.2	176.7	27.7	11.3
	H_2	95.0	80.0	87.5	17.9	15.8	208.3	187.8	198.1	43.1	9.9
	PGPR	95.0	80.0	87.5	17.9	15.8	197.2	175.5	186.4	34.7	11.0
	H_1+PGPR	101.7	86.7	94.2	27.0	14.8	213.9	198.3	206.1	48.9	7.3
	H_2+PGPR	108.3	93.3	100.8	35.8	13.8	231.1	214.4	222.8	61.0	7.2
Gypsum	50%Gr	90.0	75.0	82.5	0.0	16.7	171.7	163.3	167.5	0.0	4.9
	75%Gr	95.0	80.0	87.5	6.1	15.8	219.5	182.5	201.0	20.0	16.9
	100%Gr	100.0	85.0	92.5	12.1	15.0	205.3	186.1	195.7	16.8	9.3
	Mean-Salinity	95.0	80.0	-	-	15.8	198.8	177.3	-	-	10.8

***Ck: Control, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha, PGPR: plant growth promoting rhizobacteria, Gr: gypsum requirement, S: salinity**

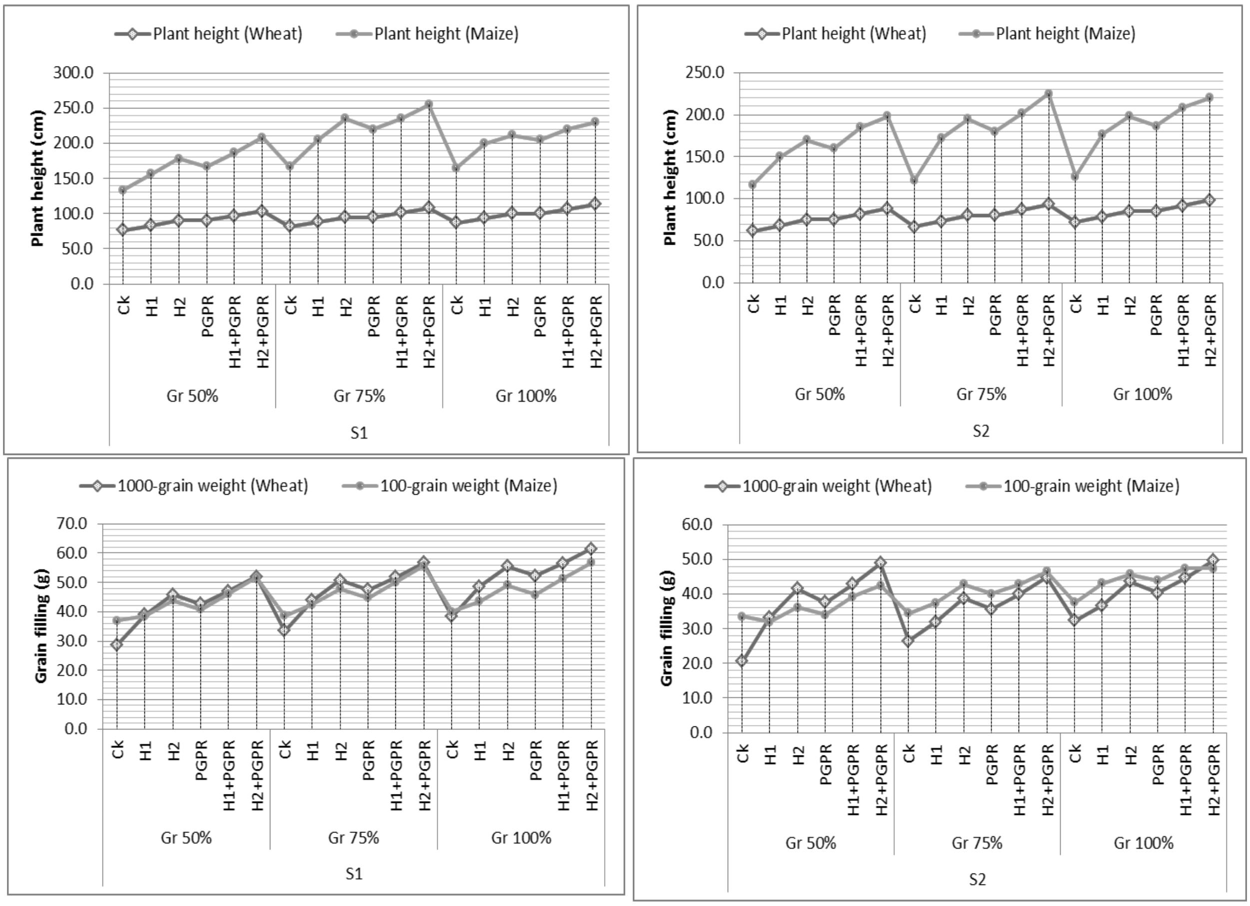
Table 7. Mean effects of gypsum, K-humate and PGPR on grain filling (g) under salinity condition

	Treatments*	Wheat (1000-grain) S_1	Wheat (1000-grain) S_2	Wheat (1000-grain) Mean	+% vs CK	- % S_1 vs S_2	Maize (100-grain) S_1	Maize (100-grain) S_2	Maize (100-grain) Mean	+% vs CK	- % S_1 vs S_2
Amendments	Ck	33.5	26.5	30.0	0.0	21.0	38.5	35.2	36.9	0.0	8.7
	H_1	43.8	33.9	38.9	29.7	22.5	41.5	37.5	39.5	7.0	9.8
	H_2	50.7	41.3	46.0	53.4	18.5	46.9	41.6	44.3	20.1	11.4
	PGPR	47.5	37.9	42.7	42.4	20.3	43.8	39.3	41.6	12.7	10.1
	H_1+PGPR	51.8	42.5	47.2	57.3	18.0	49.2	43.2	46.2	25.4	12.3
	H_2+PGPR	56.7	47.8	52.2	74.2	15.8	54.7	45.5	50.1	35.8	16.8
Gypsum	50%Gr	42.5	37.5	40.0	0.0	12.0	43.0	36.2	39.6	0.0	15.8
	75%Gr	47.3	36.3	41.8	4.5	23.4	46.6	40.7	43.7	10.4	12.6
	100%Gr	52.1	41.2	46.7	16.8	20.9	47.7	44.2	46.0	16.2	7.4
	Main-S	47.3	38.3	-	-	19.1	45.8	40.4	-	-	11.8

***Ck: Control, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha, PGPR: plant growth promoting rhizobacteria, Gr: gypsum requirement, S: salinity**

Grain filling: The weight of 1000-grain in wheat and 100-grain in maize were decreased by 19.1 and 11.8%, respectively as compared to that irrigated by normal water. In addition, application of 75 and 100% GR increased the weight of 1000-grain in wheat by 4.5 and 16.8%, respectively, while the increases of 100-grain weight in maize were 10.4 and 16.2%, respectively over that with 50%GR. Also, gypsum slightly mitigates the negative effects of salinity on grain filling in maize, whereas its decreases with 50, 75 and 100% GR due to irrigation by saline water were 15.8, 12.6 and 7.4%, respectively. These results are similar to those obtained by Cha-um *et al.,* (2011) who observed that gypsum with farm manure lessen the effects of salts on plant growth.

On the other hand, the soil amendments significantly affected grain filling in wheat and maize. The increases of 1000-grain in wheat were 29.7, 53.4, 42.4, 57.3 and 74.2%, while in maize the increases in 100-grain were 7.0, 20.1, 12.7, 25.4, and 35.8% for H_1, H_2, PGPR, H_1+PGPR and H_2+PGPR treated plants, respectively over that in CK. However, soil amendments may alleviate the harmful effect of salinity stress on 1000-grain weights in wheat, whereas its reductions due irrigation by saline water were 21.0, 22.5, 18.5, 20.3, 18.0 and 15.8%, with CK, H_1, H_2, PGPR, H_1+PGPR and H_2+PGPR, respectively. The benefits of soil amendments on plant irrigated by saline water were observed by Hassan (2016) who found that drip fertigation with 125 % recommended K with humic acid and gypsum gave high growth of plants irrigated by saline water, since Ca according to Aranda-Peres *et al.,* (2009) is needed for cell wall strengthening and provides protection against biotic and abiotic stress**.**



***Ck: Control, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha, PGPR: plant growth promoting rhizobacteria, Gr: gypsum requirement, S: salinity.**

Fig.3. Effect of salinity, gypsum, K-humate and PGPR on plant height and grain filling of wheat and maize

Grain and straw yields: The effects of irrigation water salinity and soil amendments on wheat and maize yields were significant as shown in Tables (5, 8 and 9) and Fig. (4). The data showed that the grain yields of both crops with higher salinity level (S_2) were lower than that with lower salinity level (S_2) which represents low-stressed condition by 25.1 and 12.7%, respectively, while straw yield of both crops were decreased by 25.2 and 12.6, respectively. These trends are in harmony with Manchanda and Garg, (2008), Mahajan, and Tuteja, (2005) and Queiroz, *et al.,* (2012) who observed that salinity occurred from irrigation water is responsible for increasing the salts in soil to a level that impairs plant growth such as maize.

In addition, the grain and straw yields in both crops is significantly affected by gypsum application rate from its requirement (GR). The lowest grain yields of wheat and maize were recorded with 50% GR (2.71 and 6.20 ton/ha, respectively), increased to 3.07 or 7.39 ton/ha, respectively with 75% GR, while the highest grain yields in both crops were achieved with 100% GR (3.42 and 8.13 ton/ha, respectively). The straw yields in wheat and maize were increased from 7.94 and 18.18 ton/ha, respectively with 50% GR to 8.98 and 21.69 ton/ha, respectively with 75% GR and to 10.03 and 23.87 ton/ha, respectively with 100% GR. These trends may be related to that the gypsum ionizes to $SO_4^{=}$, the best source of S which improves plant height, chlorophyll contents and green leaves number /plant (Ahmed, 2009). Also, there was a significant interaction between gypsum and salinity levels, and it may alleviate the adverse effects of salinity on crop yield, especially with maize. The grain yield of wheat and maize irrigated by saline water were decreased by 27.9 and 24.1%, respectively when treated by 50% GR, while the reductions were lowered to 25.1 and 8.5 %, respectively with 75% GR, and the lowest reductions were achieved with 100% GR (22.8 and 7.0 %, respectively). These results are agreed with those found by Makoi and Verplancke (2010) who reported that using gypsum in saline soil improves its productivity due to overcoming salt stress, and Cha-um, *et al.,* (2011) who observed that gypsum with FYM lessen plant defects because of K^+/Na increasing in plant tissues in saline soils.

Table 8. Mean effects of gypsum, K-humate and PGPR on grain yield under salinity condition

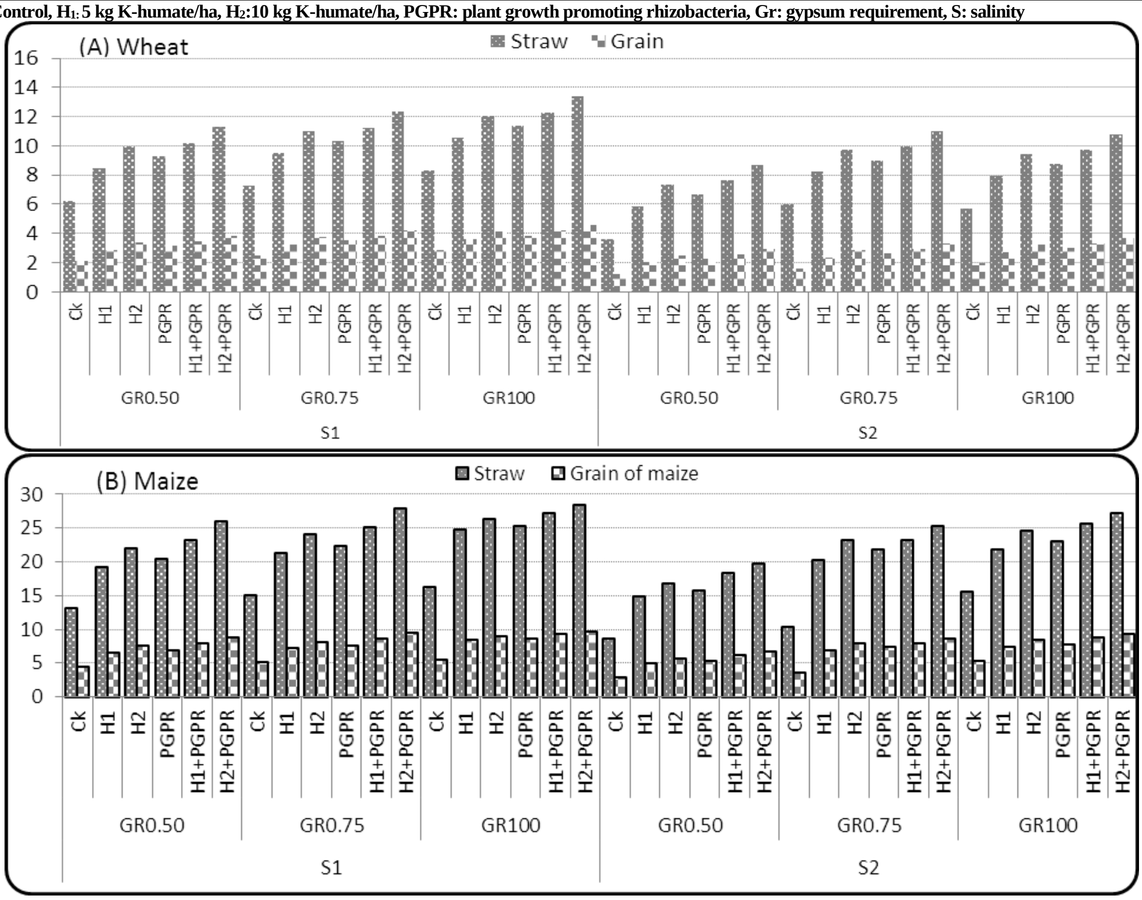
	Treatment*	Wheat S_1	Wheat S_2	Wheat Mean	+% vs CK	- % S_1 vs S_2	Maize S_1	Maize S_2	Maize Mean	+% vs CK	- % S_1vsS_2
Amendment	Ck	2.48	1.60	2.04	0.0	35.5	5.06	3.92	4.49	0.0	22.5
	H_1	3.25	2.37	2.81	37.7	27.1	7.43	6.47	6.95	54.8	12.8
	H_2	3.75	2.87	3.31	62.3	23.5	8.22	7.35	7.78	73.3	10.6
	PGPR	3.52	2.64	3.08	51.0	25.0	7.74	6.89	7.32	63.0	11.1
	H_1+PGPR	3.84	2.96	3.40	66.7	22.9	8.59	7.65	8.12	80.8	11.0
	H_2+PGPR	4.20	3.32	3.76	84.3	20.9	9.35	8.22	8.78	95.5	12.1
Gypsum	50%Gr	3.15	2.27	2.71	0.0	27.9	7.04	5.35	6.20	0.0	24.1
	75%Gr	3.51	2.63	3.07	13.3	25.1	7.72	7.06	7.39	19.2	8.5
	100%Gr	3.86	2.98	3.42	26.2	22.8	8.43	7.84	8.13	31.1	7.0
	Main-S	3.51	2.63	-	-	25.1	7.73	6.75	-	-	12.7

***Ck: Control, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha, PGPR: plant growth promoting rhizobacteria, Gr: gypsum requirement, S: salinity.**

Table 9. Straw yield of as affected by gypsum, K-humate, PGPR under salinity condition**

	Treatments*	Wheat S_1	Wheat S_2	Wheat Mean	+% vs CK	- % S_1 vs. S_2	Maize S_1	Maize S_2	Maize Mean	+% vs CK	- % S_1 vs. S_2
Amendment	Ck	7.27	4.69	5.98	0.00	35.6	14.83	11.51	13.17	0.0	22.4
	H_1	9.51	6.92	8.22	37.50	27.2	21.79	18.99	20.39	54.8	12.9
	H_2	11.00	8.42	9.71	62.40	23.5	24.11	21.56	22.84	73.4	10.6
	PGPR	10.31	7.72	9.01	50.70	25.1	22.72	20.20	21.46	62.9	11.1
	H_1+PGPR	11.25	8.66	9.96	66.60	23.0	25.21	22.44	23.82	80.9	11.0
	H_2+PGPR	12.32	9.73	11.03	84.40	21.0	27.43	24.11	25.77	95.7	12.1
Gypsum	50%Gr	9.23	6.65	7.94	0.00	28.0	20.67	15.69	18.18	0.0	24.1
	75%Gr	10.28	7.69	8.98	13.10	25.2	22.66	20.72	21.69	19.3	8.6
	100%Gr	11.32	8.74	10.03	26.30	22.8	24.73	23.00	23.87	31.3	7.0
	Main-S	10.28	7.69	-	-	25.2	22.68	19.80	-	-	12.6

***Ck: Control, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha, PGPR: plant growth promoting rhizobacteria, Gr: gypsum requirement, S: salinity**



***Ck: Control, H_1: 5 kg K-humate/ha, H_2:10 kg K-humate/ha, PGPR: plant growth promoting rhizobacteria, Gr: gypsum requirement, S: salinity.**

Fig.4. Effect of salinity, gypsum, K-humate and PGPR on a-straw and grain yield of wheat and b- in maize (ton/ha)

Concerning the effect of soil amendments, both application rates of K-humate and PGPR in addition to their interactions significantly improved growth yield. The K-humate in higher application rate (H_2) individually or combined with PGPR had the largest positive effects since it gave the highest straw and grain yields in both crops. The increases of grain yield of wheat were 37.7, 62.3, 51.0, 66.7 and 84.3%, while in maize the increases were 54.8, 73.3, 63.0, 80.8 and 95.5% due to amending the plants by H_1, H_2, PGPR, H_1+PGPR and H_2+PGPR, respectively over than that in untreated plants (CK). The increases of straw yield in both crops approximately have the same previous trend. So, the positive effect of soil amendments on crop yield was in the order as: H_2+PGPR> H_1+PGPR >H_2>H_1>CK. These results may be related to that the organic fertilizers achieve long-term stable yields (Menšík *et al.*, 2018), possible due to that their nutrients are slowly released to the plants (Adugna, 2016). In addition, according to Awwad *et al.,* (2015), addition of K-humate gave better maize yield. Also, according to Paul and Lade (2014) observed that treating the plant by PGPR gave good growth and better nutrient and chlorophyll contents.

Moreover, soil amendments may alleviate the harmful effect of salinity on crop yield. For instance, the grain of wheat irrigated by saline water was decreased by 35.5% in untreated plots (CK), while the decreases were 27.1, 23.5, 25.0, 22.9 and 20.9% in plots treated by H_1, H_2, PGPR, H_1+PGPR and H_2+PGPR, respectively. Also, maize grain with saline water was decreased by 22.5% in CK, but the decreases were 12.8, 10.6, 11.1, 11.0 and 12.1%, with H_1, H_2, PGPR, H_1+PGPR and H_2+PGPR, respectively. The same trend was detected with straw yield in both crops. The useful of the interaction between water salinity with soil amendments may be related to that the microorganisms can lessen salt stress on maize and wheat (Kotuby-Amazher *et al*., 2000) through increasing K^+/Na^+ ratio in plant tissues (Rojas-Tapias *et al.,* 2012). Also, according to Habashy and Ewees, (2011), arbuscular mycorrhizal fungi (AMF) and K-fulvate improves gypsum efficiency, soil characters, nutrients availability and positively affected the crop yield in moderate saline soils. In addition, PGPB and AMF alleviate salt stress on crops (Bacilio *et al.,* 2003 and Yildrim, *et al.,* 2008) may due to increasing the activity of some antioxidant enzymes (Stefan *et al.,* 2013) and improving salinity tolerance and growth of plants under salt conditions (Amirjani 2010) through better root and shoot growth, stress tolerance by higher K^+/Na^+ and synthesis of anti-oxidative enzymes during salt shock (Paul and Lade 2014).

CONCLUSION

This study evaluated the effect of gypsum, K-humate and plant growth promoting rhizobacteria (PGPR) on some soil properties and productivity of wheat and maize irrigated by saline water. It could be concluded that the combination of 100% GR with 10 kg K-humate ha^{-1} + PGPR was more effective on plant growth, soil properties and alleviated the harmful effects of salinity stress on crop yield.

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تأثير الجبس ،هيومات البوتاسيوم و البكتيريا المنشطة لنمو النبات على خصائص التربة وإنتاجية القمح والذرة المروية بالمياه الملحية

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أجريت تجارب حقلية في محطة البحوث الزراعية بسخا ، كفر الشيخ ، شمال الدلتا ، مصر ، في موسمين متتاليين لدراسة تأثير بعض الأضافات البيولوجية والكيميائية على إنتاجية القمح (٢٠١٩/٢٠١٨) والذرة (٢٠١٩). تمت معالجة التربة بنسبة ٥٠ و ٧٥ و ١٠٠٪ من الأحتياجات الجبسية باستخدام هيومات البوتاسيوم (٥ و ١٠ كجم/هكتار)، وبيئة البكتريا المنشطة لنمو النبات ($colony\ ml^{-1}$ 10^{8}-10^{9})، وتم ريها بالمياه المالحة (٠,٧ و٢,٤٣ ديسيسمنز/م). وتم ترتيب المعاملات في قطع منشقة مرتين مع ثلاث مكررات. أظهرت النتائج انخفاض كلا من المحصول وارتفاع النبات ودرجة امتلاء الحبوب للقمح والذرة المروية بالمياه المالحة ، مقارنة بالماء العذب. تأثر إنتاج الكتلة الحيوية وارتفاع النبات ودرجة ملء الحبوب في كلا المحصولين إيجابيا بمعدل اضافة الجبس، في حين خفف الجبس من الآثار السلبية للملوحة على الأنتاجية، خاصة مع الذرة. اضافة الهيومات بالمعدل الاعلى منفردا أو مع الـ PGPR لة تأثيرًا إيجابيًا كبيرًا على كلا المحصولين نظرًا لأنه أعطى أعلى انتاج للمحصول ومكوناتة. كما خففت المحسنات الحيوية من التأثير الضار لإجهاد الملوحة. أرتفعت قيم ECe و ESPبالتربة نتيجة ملوحة مياه الري ، بينما تأثرت قليلاً باضافة المحسنات الكيميائية أو البيولوجية. كما تأثرت الكثافة الظاهرية للتربة والمسامية الكلية سلبيا بشكل طفيف بملوحة مياه الري ، واضافة المحسنات الكيميائية أو البيولوجية. وأخيرًا ، كان اضافة ١٠٠٪ من الحتياجات الجبسية مع معدل أعلى من K-humate و PGPR أكثر فعالية في نمو النبات وخفف من الآثار الضارة لملوحة مياة الرى على نمو النبات.