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Rationalizing the Use of Water of Salinity Hazards for Irrigating Maize Grown in a Saline Sodic Soil

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SOILS of Fayoum depression are mostly salt affected and usually irrigated with water of EC around 1.2±0.2 dS m^{-1}. The current research was conducted to investigate the effects of gypsum, organic manure and humic acid applied to a saline sodic clay soil (EC 5.7 ±0.1) singly or in combinations under two irrigation systems (furrow and drip systems) at two levels of irrigation (100% of the water requirements (WR) and 75% of WR) on water saving in relation to maize productivity. The results indicated that amendments significantly increased grain yield; more upon using each singly than in combination. Increases were more pronounced with increasing the amount of irrigation water from 75% of the WR to 100% of WR. Grain yield was significantly higher in the second growing season than the first one which means a successful sustaining production of maize in the area of study. Protein content in grains ranged from 144.2 to 163.7 g kg^{-1} which is higher than the protein content of the maize imported by Egypt from other countries. Virtual water values (VWV) ranged between 0.60 to 0.89 m^3 kg^{-1} grains under drip system which was superior in the efficiency of using water for producing crop yield than values of 1.00 to 1.52 m^3 kg^{-1} under the furrow system.

Keywords: Maize, Saline sodic soil, Gypsum, humic acid, Organic manure, Virtual water .

River Nile is the main source of irrigation water in Egypt (Leger, 2004 and El-Gammal, 2012) however, its amounts has become insufficient (Rijsberman, 2006) and the Egyptian government has moved towards integrated management of drainage water to increase the budget of water supply (Abdel-Kader and Abdel-Rassoul, 2010). Most soils of Fayoum depression is salt affected located in the western desert of Egypt (Abdel Aal and Ibrahim, 2013) and uses water of salinity hazards mixed with Nile water for crop irrigation (Mustafa *et al.*, 2013). Drainage water of the agricultural drains goes mainly to Qarun lake which is located at about 43 m below sea level (Veer *et al.*, 1993). There is no natural outlet for the lake and water loss from the lake takes place only through evaporation (Wolters *et al.*, 1989). Thus, Fayoum is considered a closed drainage system (Aboul-Fotouh *et al.*, 2008). Accordingly, efficient management of low quality water to be used for irrigating such soils is vital.

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One of the important guidelines for deciding the policies of improving the water efficiency for irrigation is the term 'virtual water' (El-Sadek, 2010), which refers to the amount of water needed for producing one kg of crop yield (Wichelns, 2001). This concept is the key towards efficient management of the natural resources to create self-sufficiency and to ensure the most profitable use of the irrigation water (Renault, 2002). It is a parameter measuring the degree of water use efficiency; and it is used in different forms and with different names (Hsaiao *et al.,* 2007). Drip system is an efficient irrigation system for increasing the virtual water used in growing plants (Tognetti *et al.,* 2003), beside of its effectiveness via furrow system for managing low quality irrigation water (Bably and El-Hafez, 2013 and Mustafa *et al.*, 2013).

Maize which is a moderately sensitive crop for salinity (Yin *et al.,* 2004) , it is important crop in human food and livestock feed (Shiferaw *et al.,* 2011 and Wu & Guclu, 2013), beside involving in many industrial products such as starch, oil and fuel (FAO, 1992). Egypt is the main importer of maize in the region of North Africa (FAO, 2003) where it imports about 5 million mega grams annually (USDA, 2013). Prices of maize grains and oils are going up due to the population growth worldwide and the bio-fuel demands (McMichael, 2009 and Wright & Cafiero, 2011). Accordingly, increasing the production of maize is required to meet the overgrowing demands for food and also to decrease its imports. In this concern, some seed varieties of high productivity have been introduced in the Egyptian market as salt tolerant, *i.e.,* three way cross hybrid 2030.

Soil amendments can be used successfully for amelioration of sodic soil (Mustafa *et al.*, 2013). Gypsum is a readily available source of calcium which can substitute undesired Na^+ in soil (Qadir *et al.*, 2007). This could improve the properties of the soil and increase its productivity (Rasouli *et al.,* 2013). Organic amendments can mobilize Ca^{2+} in soil and neutralize the residual sodium carbonate in soil solutions as well as reduce soil pH and ESP of the soil (Choudhary *et al.,* 2011). Organic amendments and gypsum can minimize the undesirable effects of the low quality waters used in irrigation on the chemical and physical properties of the soil (Jalali and Ranjbar, 2009). Humic acid can also form stable soil aggregates and improve the physical properties of the soil through adsorption onto clay particles by polyvalent cations (Bronick and Lal, 2005).

The current research aims at investigating the effects of gypsum, organic matter and humic acid as soil amendments on increasing the productivity of maize plants grown in the sodic soil of Fayoum depression under two irrigation systems (furrow and drip systems) and two levels of irrigation (100% of the water requirements (WR) and 75% of WR).

Material and Methods

Soils and irrigation waters of study

Surface soil samples (0-30 cm) were collected from the area of study prior to each growing season. The samples were air dried, sieved to pass through 2 mm sieve and analyzed for their physical and chemical properties according to the standard methods outlined by Page *et al.* (1982) and Klute (1986). Physical and chemical properties of the studied soils are shown in Table 1.

TABLE 1. Physical and chemical properties of the soil under study.

Soil parameter	Sand, %	Silt, %	Clay, %	Soil texture	pH	EC, dS m^{-1}	OM, g kg^{-1}	$CaCO_3$, g kg^{-1}	ESP
Summer 2010	16.2	23.2	60.6	Clay	7.6	5.7	16.1	128.1	15.1
Summer 2011	14.6	28.3	57.1	Clay	8.0	5.8	11.1	129.9	14.8

EC: soil paste extract; pH in soil: water suspension 1:2.5; ESP: exchangeable sodium percent .

Samples of irrigation water were collected from the irrigation canals prior to each growing season and analyzed for their chemical properties (Table 2).

TABLE 2. The chemical properties of the irrigation water.

Growing season	EC dS m^{-1}	pH	SAR
Summer 2010	1.41	8.40	3.88
Summer 2011	1.21	8.30	3.24

Maize seeds and soil amendments

The seeds of maize "*Zea mays* cv three way cross hybrid 2030" were obtained from Misr HyTech Int., Egypt. Gypsum amendment (80%) was obtained from Abou-Zaebal Company for Fertilizers, Egypt. Humic acid (analytical grade, 99%) was obtained from Alpha Chemika Company. Organic manure was collected from the wastes of the animals of the farm of study. Physical and chemical properties of the used organic amendment are shown in Table 3.

TABLE 3. Chemical and physical properties of the organic manure.

Parameter	pH*	EC* dS m^{-1}	Organic-C g kg^{-1}	Total-N g kg^{-1}	Total-P g kg^{-1}	Total-K g kg^{-1}	Bulk density Mg m^{-3}
Value	7.56	2.89	551.0	10.0	9.1	19.7	698.5

*pH and EC: 1:5 w/w water extract .

The field experiment

A field experiment was conducted in Monshaet Snoras village, Fayoum governorate during the two successive summer seasons (April- August) of 2010 and 2011 to investigate the effect of using the drip irrigation system via the common used furrow irrigation system on increasing the water use efficiencies and productivity of maize in the area of study. There were two different levels of irrigation, *i.e.*, 100% of the water requirements (WR) and 75% of WR under two systems of irrigation (furrow vs. drip system). There were also six treatments of amendments as follows: (1) non amended, (2) organic manure (OM), (3) gypsum (GP), (4) humic acid (Hmc), (5) OM+GP mixture and (6) GP+Hmc mixture. This experiment was conducted in a split-split-plot design with the irrigation system as the main plots, the irrigation requirements as the sub-plots and the amendment treatments as the sub-sub-plot. The OM was applied at a rate of 24 Mg ha^{-1}, GP was applied at a rate of 10 Mg ha^{-1}, Hmc was applied at a rate of 14 kg ha^{-1}. The OM+GP rate consisted of "12 Mg +5 Mg" ha^{-1}, while the GP+Hmc rate consisted of "5Mg+7Mg" ha^{-1}. Treatments were executed in three replicates. The area of the experimental plot was 12.6 m^2. Seeds of maize were sown and all the experimental plots received the recommended doses of NP fertilizers according to the recommendations of the Egyptian Ministry of Agriculture, *i.e.*, 20 kg P ha^{-1}(as Ca-super phosphate 65.5 g P kg^{-1}) added with soil preparation and 80 kg N (as ammonium sulphate, 210 g N kg^{-1}) applied at four equal doses during soil preparation, thinning, early silking and full silking. All the agricultural practices were done as recommended. At the physiological maturity, the kernels were collected and grains were separated from the kernels using a Sheller. The grain yield was recorded and the virtual water value "VWV" (m^3 kg^{-1}) was calculated for each plot as the amount of the consumed water in m^3 for the production of one kg of crops (Renault, 2002)

$$\text{VWV } (m^3 \text{ kg}^{-1}) = \frac{\text{Consumed water } (m^3)}{\text{Yield (kg)}}$$

Irrigation water treatments

The amounts of water required for irrigation (WR) were calculated on basis of the ordinary irrigation requirements of maize in non-saline soil plus 10% leaching requirements (LR). The amount of irrigation requirement under furrow (surface) irrigation system was considered 9500 m^3 ha^{-1} (Maatouk and El-Karamity, 2005). On this basis, the two levels of irrigation water used in the current study (including 10% LR) were 10480 m^3 ha^{-1} equivalent to 100% of WR and 7860 m^3 ha^{-1} equivalent to 75% of WR. The flow of water in the irrigation canals was regulated during the field study by the flow meter (velocity-area method) as outlined by Michalski (2000) and Mustafa *et al.* (2013). Water was added in the form of 8 furrow irrigations. In case of drip irrigation, the ordinary irrigation requirements of maize was considered 5680 m^3 ha^{-1} according to Abd El-Hafez *et al.* (2001). Therefore, the two levels of irrigation water including 10% WR used under drip irrigation for 100% WR was 6250 m^3 ha^{-1} , while the corresponding one for the 75% WR was 4700 m^3 ha^{-1}. The number of irrigations was 15 irrigations.

Protein analysis in maize grains

Samples of maize grains were oven-dried for 48hr at 70°C and ground. Portions of the dried plant samples, 0.2 g each were placed in digestive tubes together with a mixture of concentrated sulfuric (H_2SO_4) acid and perchloric ($HClO_4$) acid at a ratio of 1:1 and left overnight, afterwards digested according to Ryan *et al.* (1996). Total N in the plant digest was determined using the Kjeldahl method and the crude protein content was calculated in maize grains by multiplying N% with the factor of 6.25 (Idikut *et al.*,2009).

Results and Discussion

Grain yield as affected by type of the soil amendment system and level of irrigation water

Application of soil amendments increased significantly the yield of maize grains (P=0.005). Such increases were more significantly higher due to applications of OM, GP and Hmc singly rather than the mixed applications of "OM+GP" or "GP+Hmc" (Table 4). These results are in agreement with those obtained by Lui *et al.* (2010), Chivenge *et al.* (2011), Shafi e*t al.* (2012) and Mustafa (2013) who found significant increases in the grain yield of maize with the application of organic manure. Abd Elrahman *et al.* (2012) reported significant increases in the productivity of grain yield with application of gypsum and that the combined application (organic matter +gypsum) treatment recorded higher significant increases in the grain yield than did the single amendments. However, Choudhary *et al.* (2011) found that the combined application of gypsum and organic manure caused no significant increases in the yields of rice and wheat crops over yields given by organic manure or gypsums alone.

Significant increases in grain yield were shown with increasing the amount of irrigation water from 75% of the WR to 100% of WR (P<0.001). However, there was no significant effect due to system of irrigation on the grain yield (P=0.110). Berrade and Halvorson (2012) found no significant differences in maize yield between drip and furrow irrigation; however drip irrigation used 42% less water. The grain yields were significantly higher in the second growing season than the first one (P=0.010). This guarantee sustaining production of maize in the area of study.

The obtained yield (between 6.467 to 8.933 Mg ha^{-1}) was almost near the average grain yields recorded in other countries, *i.e.,* 3.40 to 7.66 Mg ha^{-1} in China (Liu *et al*., 2010), 4.890 and 9.863 Mg ha^{-1} in Iran (Lashkari *et al*., 2012), around 9 Mg ha^{-1} in France and around 8.8 Mg ha^{-1} in Italy (USDA, 2013).

Protein content in maize grains as affected by type of the soil amendment, system and level of irrigation water

Protein content in maize grains increased significantly under drip irrigation system than under furrow irrigation system (P<0.001). The increases were more obvious with increasing the amount of irrigation water from 75% to 100% of WR (P<0.001). Also, the applied soil amendments caused further significant increases in the grain yield (P<0.001), especially "OM+GP" (Table 5). Protein content ranged from 144.2 to 163.7 g kg^{-1}. These values were greater than those recorded in maize grains of the high-oil inbred line, By804, and the regular inbred line, B73 in China (Guo *et al.*, 2013) which ranged between 86.7 and 121.9 g kg^{-1}, respectively. They also exceeded values in Turky, which varied between 89.1-116.5 g kg^{-1} (Idikut *et al.*, 2009). Thus the grains obtained in the current study were of higher protein content than those of the maize grains imported from China and Turkey. Even between the main exporters of maize grains worldwide which are Argentina and Brazil (USDA, 2013), protein content in grown therein maize is higher, where the protein content ranged from 88.0 to 119.0 g kg^{-1} in Argentine maize race (Robutti *et al.* ,2000) and from 105.1 to 115.8 g kg^{-1} in the Brazilian maize (Mittelmann *et al.*, 2011).

TABLE 4. Maize grain yield (kg ha^{-1}) as affected by the type of soil amendment, system and level of irrigation water .

Treatment	Season	Furrow irrigation		Drip irrigation		
		75% WR	100% WR	75% WR	100% WR	Grand mean
Non-amended	1st	6,467	6,633	6,633	7,100	6,467
	2nd	6,733	6,833	6,900	7,467	6,733
	mean	6,600	6,733	6,767	7,283	6,600
Organic manure (OM)	1st	6,933	8,067	7,100	8,433	6,933
	2nd	7,100	8,167	7,200	8,933	7,100
	mean	7,017	8,117	7,150	8,683	7,017
Gypsum (GP)	1st	6,800	8,033	7,000	8,367	6,800
	2nd	6,967	8,300	7,033	8,833	6,967
	mean	6,883	8,167	7,017	8,600	6,883
Humic acid (Hmc)	1st	6,733	8,000	7,000	8,100	6,733
	2nd	7,200	8,067	7,002	8,533	7,200
	mean	6,967	8,033	7,001	8,317	6,967
"OM +GP"	1st	6,733	8,001	6,967	7,967	6,733
	2nd	6,833	8,000	6,965	8,367	6,833
	mean	6,783	8,001	6,966	8,167	6,783
"GP+Hmc"	1st	6,700	8,400	6,900	7,633	6,700
	2nd	6,800	8,402	6,933	7,867	6,800
	mean	6,750	,8401	6,917	7,750	6,750

Main effects of the system and level of irrigation water

	75% WR	100% WR	Mean
Furrow system	6,833	7,910	7,371
Drip system	6,969	8,133	7,552
Mean	6,902	8,021	

LSD(0.05): season (885), irr level (885), amend (511), season× WR level (1,257), season× amend (1,032), WR level× amend(1,032), season ×amend× irr level (1,361). 1st & 2nd denote seasons .

TABLE 5. Protein content in grains (g kg^{-1}) as affected by type of the soil amendment, system and level of irrigation water .

Treatment	Season	Furrow irrigation		Drip irrigation		Grand mean
		75% WR	100% WR	75% WR	100% WR	
Non-amended	1st	141.3	141.6	142.1	143.2	142.0
	2nd	141.2	141.4	141.8	142.5	141.7
	mean	141.2	141.5	141.9	142.9	141. 9
Organic manure (OM)	1st	144.3	152.9	151.6	163.7	153.1
	2nd	144.0	152.7	151.5	162.1	152. 7
	mean	144.2	152.8	151.5	162.9	152.9
Gypsum (GP)	1st	143.9	152.4	151.2	162.6	152.5
	2nd	143.3	152.2	151.1	160.3	151.7
	mean	143.6	152.3	151.1	161.5	152.1
Humic acid (Hmc)	1st	141.5	151.1	150.5	158.5	150.4
	2nd	141.8	150.7	150.4	157.6	150.1
	mean	141.6	150.9	150.4	158.0	150.3
"OM +GP"	1st	141.6	151.2	150.7	158.9	150.6
	2nd	141.8	151.0	150.4	157.4	150.1
	mean	141.7	151.1	150. 6	158.1	150.4
"GP+Hmc"	1st	141.5	151.1	151.0	158.6	150.6
	2nd	141.3	151.1	150. 7	156.6	149.9
	mean	141.4	151.1	150.8	157.6	150.2
Main effects of the system and level of irrigation water						
		75% WR	100% WR	Mean		
Furrow system		142.3	149.4	145.8		
Drip system		150.0	156.8	153.4		
Mean		146.2	153.2			

LSD(0.05): season (2.5), irr sys (2.5), irr level (2.5), amend (1.5), amend× irr sys (2.9), amend ×irr lev (2.9), irr sys× irr level× amend(1. 6). 1st & 2nd denote seasons .

Virtual water value as affected by type of the soil amendment, system and level of irrigation water

The virtual water values (VWV) were significantly lower with the application of soil amendments($P<0.001$), especially under the drip irrigation system rather than the furrow system (Table 6) . These values ranged from 0.60 to 0.89 m^3 kg^{-1} grains under drip irrigation corresponding to 1.00 to 1.52 m^3 kg^{-1} grains under furrow irrigation. This was more pronounced with the application of 75% of WR than 100% of WR

(P<0.001). Irrigation using drip system was of lower VWV values than the furrow system (P<0.001). There was no significant difference between the two growing seasons (P=0.050). Sheng *et al.* (2009) stated that soil salinity is one of the main abiotic factors limiting crop production and the system of irrigation which attains greater water use efficiency guarantees low salt inputs for the sodic soil of study . Renault (2002) reported that VWV for irrigated maize ranged between 0.7 to 1.9 kg m^3 which were rather comparable with the values obtained herein in the current study. Thus, maize under drip irrigation systems using water of medium salinity hazards could be of a positive effect. This indicates that drip irrigation system would be preferred in Fayoum region because of the shortage in the amounts of irrigation water.

TABLE 6. Virtual water value "VWV" (m^3 kg^{-1}) as affected by the application of soil amendment, system and level of irrigation water .

		Furrow irrigation		Drip irrigation		Grand mean
		75% WR	100% WR	75% WR	100% WR	
Zero amendment	1st	1.23	1.25	0.69	0.82	1.23
	2nd	1.16	1.54	0.68	0.84	1.16
	mean	1.20	1.37	0.68	0.83	1.20
Organic manure (OM)	1st	1.27	1.33	0.68	0.79	1.27
	2nd	1.11	1.28	0.65	0.70	1.11
	mean	1.18	1.30	0.67	0.74	1.18
Gypsum (GP)	1st	1.04	1.52	0.61	0.89	1.04
	2nd	1.12	1.27	0.67	0.71	1.12
	mean	1.09	1.37	0.64	0.79	1.09
Humic acid (Hmc)	1st	0.92	1.52	0.60	0.89	0.92
	2nd	1.09	1.30	0.67	0.73	1.09
	mean	1.00	1.39	0.64	0.81	1.00
"OM +GP"	1st	1.14	1.39	0.68	0.81	1.14
	2nd	1.15	1.32	0.68	0.75	1.15
	mean	1.14	1.35	0.68	0.78	1.14
"GP+Hmc"	1st	1.14	1.33	0.67	0.78	1.14
	2nd	1.15	1.25	0.68	0.79	1.15
	mean	1.15	1.28	0.68	0.79	1.15

Main effects of the system and level of irrigation water

	75% WR	100% WR	Mean
Furrow system	1.12	1.35	1.22
Drip system	0.66	0.79	0.72
Mean	0.83	0.99	

LSD(0.05): season (0.12), irr sys (0.12), irr level (0.12), amend (0.07), season× WR level (0.17), season× amend (0.14), irr sys × irr level (0.17), irr level ×amend (0.14), season ×amend× irr level (0.19), season ×amend× irr level (0.19) season ×irr sys× irr level× amend (0.22). 1st & 2nd denote seasons .

Conclusion

The Egyptian government must take drastic steps towards increasing the production of maize grains in Egypt as a strategic crop for human food and animal feeding. These steps may include (1) encouraging farmers to switch their irrigation system from the furrow to the drip system (2) providing guidelines on the importance of the application of soil amendments (3) determining fair rates for the price of maize grains, beside of providing a real subsiding to the production requirements of maize.

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ترشيد استخدام مياه ذات مخاطر ملحية لري محصول الذرة النامي في أرض ملحية صودية

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يعتبر معظم أراضي منخفض الفيوم متأثرة بالأملاح والتي تروي بمياه ذات توصيل كهربي حوالي 1.2 ± 0.2 dS m^{-1} وبالتالي تهدف الدراسة التالية إلي التحقق من تأثير إضافة الجبس و المواد العضوية و حمض الهيوميك إلي أرض ملحية صودية (EC 5.7 ±0.1)إما بصورة فردية أو مختلطة تحت نظامي الري بالغمر والري بالتنقيط باستخدام مستوين من مياه الري (100 ٪ و 75 ٪ من الاحتياجات المائية)علي التوفير في مياه الري وعلاقتها بإنتاجية محصول الذرة وقد أشارت النتائج إلى أن استخدام محسنات التربة احدث زيادة في محصول الحبوب خصوصا المعاملات الفردية والتي تفوقت علي المعاملات المختلطة وكانت تلك الزيادات أكثر وضوحا مع زيادة كمية مياه الري من 75 ٪ إلى 100 ٪ من الاحتياجات المائية ومن الجدير بالذكر أن محصول الحبوب المتحصل عليه خلال الموسم الثاني كان أكبر من ذلك المتحصل عليه من الموسم الأول وهذا يشير إلي إمكانية الاستدامة في إنتاج الذرة في الأرض موضع الدراسة ، كما أوضحت النتائج أن محتوى البروتين يتراوح في حبوب الذرة بين 144,2 إلي 163,7 جم كجم$^{-1}$ متفوقا بذلك علي محتوى البروتين الموجود في حبوب الذرة المستوردة إلي مصر من بلدان أخري. هذا وقد تراوحت قيم المياه الافتراضية (VWV) لإنتاج الحبوب بين 0,60–0,89 م^{3} كجم$^{-1}$ تحت نظام الري بالتنقيط والذي اظهر تفوقا في كفاءة استخدام المياه في إنتاج المحاصيل مقابل قيم 1,00–1,52 م^{3} كجم$^{-1}$ والمتحصل عليها تحت نظام الري بالغمر.