Annals of Agric. Sci., Moshtohor **ISSN 1110-0419**
Vol. 56(3) (2018), 799 – 810 **http://aasj.bu.edu.eg/index.php**

The Feasibility of Using Microbial, Organic and Mineral Amendments for Ameliorating a Saline-Sodic Soil and Their Implications on the Productivity of Sugar beet and Rice Grown Thereon

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Abstract

The current study aims at evaluating the feasibility of amending a saline-sodic soil of (EC = 12.38 dSm^{-1}, ESP = 23.38 and $CaCO_3$ content = 25.44 g kg^{-1}) with microbial amendment (*Azolla* + Cyanobacteria extract 1:1), organic amendment (compost) and mineral amendments (elemental sulfur, dilute H_2SO_4, dilute H_3PO_4, phosphogypsum, and aluminum sulfate) either solely or in combinations to ameliorate such a soil. This investigation was carried out under the field conditions at El-Rowad village, South of El-Hosainiya Plain, North East of the Nile Delta, Sharkia Governorate, Egypt for two successive seasons *i.e* a winter season (of 2015 - and 2016) under sugar beet and the summer season of (2016) under rice crop. The investigated soil was irrigated with a low-quality water (EC, 1.58±0.06 and SAR, 7.51±0.13). *Azolla* and Cyanobacteria extract (1:1)was used at a rate of50L ha^{-1}. Compost was used at a rate of 9.02 Mg ha^{-1} before growing sugar beet only. Applications of sulfuric and phosphoric acids were carried out through irrigation water. Results revealed that the studied microbial, organic and mineral amendments significantly decreased soil EC and ESP during both seasons of study, and furthermore significantly improved the yields of both sugar beet (root and foliage) and rice (grains and straw). The interactions between these treatments were also of significant effect, however, the interaction among. "sulfur + compost + microbial inoculation with *Azolla* and Cyanobacteria extract" was the most efficient one for improving the chemical characteristics of the soil (EC and ESP) as well as the yield of plants grown thereon. Where the soil EC decreased to 7.88±1.22 dSm^{-1} while the ESP values reached 7.36±0.25. Root and foliage yields of sugar beet were 13.38 and 5.13 Mg ha^{-1}, respectively on the dry weight basis whereas the grain and straw yields of rice were 7.24 and 14.34 Mg ha^{-1} respectively. Accordingly, the triple applications of sulfur + compost + microbial inoculation with *Azolla* and Cyanobacteria extract are recommended to ameliorate the saline-sodic soil on one hand and to attain better crop yield on the other one.

Keywords: Saline-sodic soil; chemical properties; improvement; mineral amendments; compost; mixed *Azolla* and Cyanobacteria extract; sugarbeet and rice crop

Introduction

Soil salinity is one of the main issues that threats crop production in many arid and semi-arid areas worldwide (Kumar, 2012). In Egypt, most of the salt-affected soils are located within the Nile Delta region (Gehad, 2003; FAO, 2005 and Ouda and Zohry, 2016). These soils account for 55% of the total cultivated areas in the northern Nile Delta whereas, these soils represent only 20% of the cultivated area in Southern Delta and 25% of the cultivated areas in Upper Egypt (El-Banna *et al.*, 2004). Furthermore, Wadi El-Natroun, Tal El-Kebeir, the Oases, and El-Fayoum province are considered salt-affected soils (Gehad, 2003 and Farid *et al*., 2014).

Saline-sodic soils are characterized by EC_e values exceeding 4 dSm^{-1}, pH < 8.5, and ESP > 15 (O'Geen, 2015). These soils contain high concentrations of soluble salts and exhibit high percentages of the exchangeable sodium (Cardon and Mortvedt, 2001), where the dominant salts are sodium sulfate (Na_2SO_4), sodium carbonate and bicarbonate (Na_2CO_3 and $NaHCO_3$) (Negm, 2017). To overcome the sodicity problem, sodic soils are amended with soluble calcium salts to substitute the sorbed $Na^+$and then water is brought to the reaction to flush the replaced Na^+ out of the root zone (Cardon and Mortvedt, 2001). The common source of calcium is thought to be gypsum which can substitute undesired Na^+ in soil (Qadir *et al.*, 2007). However, phosphogypsum (PG) is preferable than ordinary gypsum in ameliorating saline-sodic because it takes part in increasing the solubility of soil $CaCO_3$ and hence, the release of more soluble Ca^{2+} ions in soils (Abd El-Fattah, 2014). Also, the organic amendments can be used effectively to ameliorate salt-affected soils (Feizi *et al.*, 2010) either solely or in combination with gypsum (Kamel *et al*., 2016). Depending on the native soil $CaCO_3$, soil amelioration might also take place through amending soils with either sulfur (S̀), sulfuric acid (H_2SO_4) (Mc Cauley and Jones, 2005), aluminum sulfate $[Al_2(SO_4)_3].18H_2O$ (Farag *et al.*, 2013) or phosphoric acid (H_3PO_4) which produce an acidic-homogenous solution and therefore increase the dissociation of soil $CaCO_3$ presented in soil (Gharaibeh *et al.*, 2012). Generally, all the investigated amendments decrease soil pH, EC and ESP (Mahdy, 2011 and Farag *et al.*, 2013). Other biological approaches are recommended to increase the tolerance of plants grown on salt affected soil. For example, cyanobacteria (blue-green algae) chelates soluble sodium ions from soil solution (Nisha *et al.*, 2017), increases the chlorophyll content of leaves and also an accumulation of osmoprotectant compounds such as proline and phenols in the plant root (Mostafa *et al.*, 2013). *Azolla* is another example of the biological ameliorating agents for slat affected soil. It produces phytohormones like cytokinins, gibberellins, and auxins that enhance plant growth under saline conditions (Elsherif *et al.*, 2013). Moreover, it excretes polysaccharides, peptides, lipids, organic acids which can reduce soil pH, while on the other hand, adsorb both Na^+ and Mg^{2+} ions presented in soil solution and therefore prevents the negative consequences of these ions on soils and growing plants (Aref *et al.*, 2011). These microbial treatments are thought also, to improve soil physical and chemical properties under saline conditions (Hanna *et al.*, 2013).

Thus, the current investigation aims at evaluating the impacts of amending a saline-sodic soil, irrigated with a low quality water (EC = 1.60 dSm^{-1}), with mineral (elemental sulfur, phosphogypsum, aluminum sulfate, sulfuric acid and phosphoric acid), organic (compost) and microbial (mixed *Azolla* and Cyanobacteria extracts) amendments to improve the chemical characteristics of a saline-sodic soil *i.e.* pH and EC and hence increase the productivity of sugar beet and rice crops grown on such a soil.

Materials and Methods

Materials of study

A field experiment was conducted on a saline-sodic soil located between latitudes31^0 8' 12.461" N and longitudes 31^0 52' 15.496" E at El-Rowad village, South of El-Hosainiya plain, North East of the Nile Delta, Sharkia Governorate, Egypt for two the winter season of 2015-2016 and the summer season of 2016. The physiochemical properties of the investigated soil are presented in Table 1. Irrigation water samples were collected during the winter and summer seasons and analyzed for their chemical characteristics whose results are presented in Table 2.

Table 1. Physiochemical properties of the studied soil before planting.

Physical characteristics								
Particle size distribution %				Textural class	BD Mgm^{-3}	FC	WP	AV
C. sand	F. sand	Silt	Clay			(%, v/v)		
2.1	32.7	16.9	48.4	Heavy clay	1.4	38.9	19.7	19.2

Chemical characteristics											
EC dSm^{-1}	Soluble ions ($mmol_cL^{-1}$)								pH	SAR	ESP
	Ca^{++}	Mg^{++}	Na^+	K^+	$CO_3^=$	HCO_3^-	Cl^-	$SO_4^=$			
13.28	23.76	37.01	103.12	1.44	0.00	5.76	81.12	78.45	8.10	18.72	23.38

C. sand: coarse sand, F. sand: fine sand, BD: bulk density, FC: field capacity, WP: wilting point, AV: available water, EC: determined in soil paste extract, pH: determined in (soil: water suspension, 1:2.5), SAR: sodium adsorption ratio, ESP: exchangeable sodium percentage

Table 2. Chemical properties of water (El-Salam Canal used for irrigation).*

pH	EC dSm^{-1}	**Soluble ions ($mmol_cL^{-1}$)**								SAR	SSP (%)
		Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}		
The winter season (2015/2016)											
7.71	1.62	1.27	3.13	10.96	0.35	0.00	1.13	11.76	2.82	7.41	69.76
The summer season (2016)											
7.65	1.54	1.17	2.79	10.72	0.33	0.00	1.58	11.42	2.01	7.60	71.42

SAR: sodium adsorption ratio which is equivalent to $Na^+ / [Ca + Mg / 2]^{1/2}$, SSP: soluble sodium percentage which is equivalent to $[Na^+]$ ($mmol_cL^{-1}$) / $[Ca^{2+} + Mg^{2+} + Na^+ + K^+]$ ($mmol_cL^{-1}$) × 100
*El-Salam Canal is mix water 1:1 agricultural drainage and Nile water

The microbial inoculants by *Azolla pinnata* and Cyanobacteria (*Anabeanaoryza and Nostoc muscorum*) were kindly provided by the Agricultural Microbiology Research Department, Soils & Water and Environment Research Institute (SWERI), Agricultural Research Center (ARC), Giza, Egypt. Seeds of sugar beet (*Beta vulgaris* L.) cultivar Nabila (Multi-germ seedsfrom France) and rice (*Oriza sativa* L.) cultivar Giza 178 were obtained from Egyptian Agricultural Organization and Ministry of Egyptian Agriculture for seeds of sugar beet and rice, respectively. The compost was obtained from the Egyptian Italian Co. for Organic Fertilizers and ITS Derivatives. Physical and chemical characteristics of the investigated compost are presented in Table 3.

Table 3. Chemical properties of the compost used in the study.

Parameter	**Bulk density (Mgm^{-3})**	**Moisture content (%)**	**pH (1:10)**	**EC (1:10) (dSm^{-1})**	**OM (gkg^{-1})**	**Organic carbon (gkg^{-1})**	**Ash (%)**
Value	0.70	20.0	8.1	4.34	390	226.20	61.0
Parameter	**C:N**	**Total N (gkg^{-1})**	**NH_4-N ($mgkg^{-1}$)**	**NO_3-N ($mgkg^{-1}$)**	**Total P (gkg^{-1})**	**Total K (gkg^{-1})**	
Value	16.16 : 1	14.0	520	90	6.50	9.10	

Field experiment

To evaluate the effectiveness of the amendments used for ameliorating the saline-sodic soil understudy two growing seasons were considered in this study. A winter season was cultivated with sugar beet crop whereas the summer one was cultivated with rice crop. The experimental design was a split-split design including 24 treatments in three replicates (with/without microbial inoculants; with/without compost, and 5 mineral amendments). The plot area was 11.08 m^2. The microbial treatments *i.e.Azolla pinnata* and *Cyanobacteria* were arranged in the main plots, compost treatment was allocated in the subplots and the different mineral amendments were placed in the sub-subplots *i.e.* elemental sulfur (S), phosphogypsum (PG), aluminum sulfate $[Al_2(SO_4)_3].18H_2O$, phosphoric acid (H_3PO_4) and sulfuric acid (H_2SO_4).

Sulfur was added at a rate of 0.48 Mg ha^{-1} prior to seed cultivation and then mixed with the top surface layer (0-30 cm) by a plow. Phosphogypsum, [13% S, 6% Ca and 0.50% P_2O_5] was added to the soil at a rate of 3.66 Mg ha^{-1} before cultivation. Aluminum sulfate was added at a rate of 3.30 Mg ha^{-1} before cultivation. Compost was added at a rate of 9.02 Mg ha^{-1} before growing sugar beet only.

The winter season (sugar beet)

The seeds of sugar beet plants were soaked in *Azolla* and Cyanobacteria extract (1:1) for 2 hours before sowing. Sugar beet seeds were planted on the 23rd of September 2015 at a rate of 9.5 kg ha^{-1} on ridges (within the top third of ridge on the Southern side; width of the ridge was 60 cm in hills, 20 cm apart). Four seeds of sugar beet were placed per hill. N, P, and K fertilizers were added at the doses recommended by the Egyptian Agriculture Ministry *i.e.*, 190.40 kg N ha^{-1}, 15.59 kg P ha^{-1} and 49.36 kg K ha^{-1} in the form of ammonium nitrate (33.5% N), Ca-super phosphate (12.5% P_2O_5) and potassium sulfate (50% K_2O), respectively. The sugar beet plants were thinned to one plant per hill after 30 and 55 days from sowing, *i.e.*, 23/10 and 17/11 2015, respectively. Plants were sprayed with *Azolla* and Cyanobacteria extract (1:1) at a rate of 50 L ha^{-1} by spraying motor at the 28th, 57th and 92nd days from sowing. Phosphoric and sulfuric acids were added at a rate of 1.46 Mg ha^{-1} through the dripping irrigation system at five periods *i.e.* 0, 29, 49, 68 and 89 days after the sowing of sugar beet. After 195 days from sowing, the yield of each plot was estimated. Plants were then separated into root and foliage, dried at 70 °C and then weighted to estimate their dry weights.

The summer season (rice)

Rice cultivar Giza 178 (*Oriza sativa* L.) was planted on the 22nd of April 2016. Rice grains were sown by the manual broadcasting method at a rate of 293 kg $ha.^{-1}$. N, P, and K fertilizers were added as recommended by the Egyptian Ministry of Agriculture *i.e.* 164.22 kg N ha^{-1} in the form of urea (46% N), 15.59 kg P ha^{-1} in the form of Ca-super phosphate (12.5% P_2O_5) and 4.76 kg K/100 L^{-1} ha^{-1} in the form of potassium sulfate (50% K_2O). Zinc sulfate was applied as a foliar application after drying the soil for two days at a rate of 4.76 kg $ZnSO_4$/200 L^{-1} ha^{-1} after 18 and 48 days from planting, respectively. All the agricultural practices were followed as usual. *Azolla* and Cyanobacteria extract (1:1) were applied to rice through the irrigation system at a rate of 50 L ha^{-1} at three equal doses after 20, 40 and 60 days from sowing. Phosphoric and sulfuric acids were applied at a rate of 1.46 Mg ha^{-1} through the irrigation system (by plastic containers provided with holes for dripping of acids) at five periods *i.e.* 7, 21, 38, 52 and 66 days after sowing rice. After 116 days from sowing, plants were harvested and the yield estimated from each plot. The plants were washed several times with deionized water, separated into grains and straw, dried at 70 °C and the dry weight (Mg ha^{-1})of both was estimated for each plot.

Soil, water, and plant analyses

Physical characteristics of the investigated soil were determined according to Gee and Bauder (1986) and Klute (1986); whereas, the chemical ones were determined according to Page *et al*. (1982). The chemical characteristics of irrigation water were determined also according to Page *et al.* (1982).

Plant samples of leaves were taken from each plot after 97 and 34 days of sowing the sugar beet and rice, respectively for determining free proline according to Bates *et al*. (1973).

Data processing

All the obtained data were statistically analyzed and compared by using least significant difference (L.S.D) at 5% level of probability according to the procedure described by Gomez and Gomez(1984).

Results

Soil EC_e and ESP as affected by the microbial, organic and mineral amendments

Soil inoculation with *Azolla* and Cyanobacteria significantly decreased the soil EC_e during the winter and the summer growing seasons. The decrease was by 13.7 and 19.9% for the winter and the summer seasons, respectively compared with the non-inoculated control soil (Table 4). Likewise, the values of ESP decreased in such soil (Table 5). The compost application also significantly decreased the soil EC_e and ESP during both the winter and summer seasons. The decreases in the soil EC_e were by 23.1 and 3.2% for the winter and summer growing seasons, respectively whereas the corresponding decreases in the soil ESP were by 22.3 and 16.1% for the winter and the summer seasons, respectively. Application of sulfur, phosphogypsum, aluminum sulfate, phosphoric acid and sulfuric acid recorded further significant decreases in the values of both the soil EC_e and ESP. In this concern, S was found to be the most effective mineral amendments in decreasing the soil EC_e and ESP. The lowest values of soil EC_e and ESP were recorded for the treatment consisting of sulfur + compost + "Azolla and Cyanobacteria extract" (6.63 and 7.80 dSm^{-1} for EC and 5.49 and 6.33 for ESP during the winter and summer season, respectively). Generally, the values of soil EC and ESP were significantly higher in the summer growing season than those occurred in the winter growing one.

Table 4. Soil EC_e as affected by the microbial inoculation (M), compost (C) and mineral amendments (A).

Treatment	The winter season (sugar beet)							The summer season (rice)						
	Non	S	PG	AS	PA	SA	Mean	Non	S	PG	AS	PA	SA	Mean
Without inoculation														
-C	12.27	11.54	12.20	11.93	12.20	12.05	12.03	17.46	9.95	12.44	16.81	13.74	11.21	13.60
+C	10.62	7.42	10.12	8.75	9.84	9.39	9.35	17.34	9.67	12.27	15.81	13.35	10.20	13.11
Mean	11.44	9.48	11.16	10.34	11.02	10.72	10.69	17.40	9.81	12.36	16.31	13.54	10.71	13.35
With inoculation														
-C	11.17	10.04	10.30	10.13	10.77	10.50	10.48	14.42	8.02	10.19	12.07	11.45	8.95	10.85
+C	8.77	6.63	8.23	7.54	8.42	8.22	7.97	14.05	7.80	10.16	11.89	10.81	8.59	10.55
Mean	9.97	8.34	9.26	8.84	9.60	9.36	9.23	14.24	7.91	10.17	11.98	11.13	8.77	10.70
Means of compost														
-C	11.72	10.79	11.25	11.03	11.49	11.27	11.26	15.94	8.99	11.32	14.44	12.59	10.08	12.22
+C	9.69	7.02	9.17	8.15	9.13	8.81	8.66	15.69	8.74	11.21	13.85	12.08	9.39	11.83
Mean	10.71	8.91	10.21	9.59	10.31	10.04	9.96	15.82	8.86	11.26	14.15	12.33	9.74	12.03
LSD at 0.05	**M:**0.08, **C:**0.04, **MC:**0.06, **A:**0.03, **MA:**0.04, **CA:**0.04, **MCA:**0.05							**M:**0.03, **C:**0.02, **MC:**0.03, **A:**0.03, **MA:**0.04, **CA:**0.04, **MCA:**0.05						

-C: without compost; +C: with compost; Non: without application of amendments; S: sulfur; PG: phosphogypsum; AS: aluminum sulfate; PA: phosphoric acid; SA: sulfuric acid

Note: the compost treatment (with) in the summer season is residual compost

Table 5. Soil ESP as affected by the microbial inoculation (M), compost (C) and mineral amendments (A).

Treatment	The winter season (sugar beet)							The summer season (rice)						
	Non	S	PG	AS	PA	SA	Mean	Non	S	PG	AS	PA	SA	Mean
Without inoculation														
-C	20.59	11.08	14.31	13.05	15.36	15.47	14.97	23.24	10.69	12.41	12.75	12.52	11.52	13.85
+C	16.30	8.89	10.54	9.20	11.01	11.10	11.17	20.47	8.76	9.58	10.51	10.14	9.35	11.47
Mean	18.44	9.98	12.42	11.12	13.18	13.28	13.07	21.85	9.72	10.99	11.63	11.33	10.43	12.66
With inoculation														
-C	12.51	6.44	7.85	7.48	8.25	8.45	8.50	13.52	7.88	8.29	8.55	8.93	8.21	9.23
+C	10.95	5.49	6.41	5.91	6.66	6.98	7.06	12.29	6.33	7.21	7.39	7.31	6.81	7.89
Mean	11.73	5.96	7.13	6.70	7.45	7.71	7.78	12.90	7.10	7.75	7.97	8.12	7.51	8.56
Means of compost														
-C	16.55	8.76	11.08	10.26	11.80	11.96	11.73	18.38	9.28	10.35	10.65	10.72	9.86	11.54
+C	13.62	7.19	8.47	7.56	8.84	9.04	9.12	16.38	7.54	8.40	8.95	8.72	8.08	9.68
Mean	15.09	7.97	9.78	8.91	10.32	10.50	10.43	17.38	8.41	9.37	9.80	9.72	8.97	10.61
LSD at 0.05	**M:** 0.011, **C:**0.024, **MC:**0.034, **A:**0.026, **MA**: 0.037, **CA:** 0.037, **MCA:**0.052							**M:**0.001, **C:**0.001, **MC:**0.001, **A:**0.001,**MA**: 0.001, **CA:** 0.001, **MCA:**0.001						

-C: without compost; +C: with compost; Non: without application of amendments; S: sulfur; PG: phosphogypsum; AS: aluminum sulfate; PA: phosphoric acid; SA: sulfuric acid

Note: the compost treatment (with) in the summer season is residual compost

Free proline concentration in leaves (mg g^{-1} fresh leaf) of sugar beet and rice as affected by the microbial, organic and mineral amendments

Significant increases occurred in proline concentration in leaves of both sugar beet and rice plants due to the application of *Azolla* and Cyanobacteria extract, compost and mineral amendments in both the two seasons as shown in Table 6.

Table 6. Effect of microbial inoculation (M), compost (C) and the mineral amendments (A) on the free proline concentration in leaves (mg g^{-1} fresh leaf) of sugar beet and rice plants.

Treatment	Free proline concentration (mg g^{-1} fresh leaf) after 97 days from the planting							Free proline concentration (mg g^{-1} fresh leaf) after 34 days from the planting						
	Sugar beet (the winter season)						Mean	Rice (the summer season)						Mean
	Non	S	PG	AS	PA	SA		Non	S	PG	AS	PA	SA	
	Without inoculation													
-C	0.25	0.60	0.49	0.53	0.42	0.43	0.45	0.85	1.22	1.09	0.94	0.96	1.33	1.06
+C	0.31	0.73	0.60	0.64	0.51	0.53	0.55	1.16	1.66	1.48	1.26	1.31	1.80	1.44
Mean	0.28	0.67	0.55	0.58	0.47	0.48	0.50	1.00	1.44	1.29	1.10	1.13	1.56	1.25
	With inoculation													
-C	0.34	0.80	0.66	0.71	0.57	0.58	0.61	1.46	2.09	1.87	1.60	1.64	2.27	1.82
+C	0.42	0.98	0.81	0.87	0.69	0.70	0.75	1.97	2.84	2.53	2.16	2.23	3.07	2.47
Mean	0.38	0.89	0.74	0.79	0.63	0.64	0.68	1.71	2.47	2.20	1.88	1.94	2.67	2.14
	Means of compost													
-C	0.29	0.70	0.58	0.62	0.49	0.50	0.53	1.15	1.66	1.48	1.27	1.30	1.80	1.44
+C	0.37	0.86	0.71	0.76	0.60	0.62	0.65	1.56	2.25	2.01	1.71	1.77	2.43	1.95
Mean	0.33	0.78	0.64	0.69	0.55	0.56	0.59	1.36	1.95	1.74	1.49	1.53	2.12	1.70
LSD at .05	**M:** 0.01, **C:**0.01, **MC:**0.02, **A:**0.01, **MA:**0.01, **CA:**0.01, **MCA:**NS							**M:** 0.01, **C:**0.02, **MC:**0.03, **A:**0.02, **MA:**0.02, **CA:**0.02, **MCA:**0.03						

-C: without compost; +C: with compost; Non: without application of amendments; S: sulfur; PG: phosphogypsum; AS: aluminum sulfate; PA: phosphoric acid; SA: sulfuric acid

Note: the compost treatment (with) in the summer season is residual compost

Root and foliage yields of sugar beet (Mg ha^{-1}) as affected by the microbial, organic and mineral amendments

Significant increases occurred in both root (17.8 %) and foliage (14.8%) yields of sugar beet (on a dry weight basis) due to the application of *Azolla* and Cyanobacterial extract (Table 7). Likewise, yields of both root and foliage significantly increased by 18.5 and 18.5%, respectively owing to the application of compost. Furthermore, the mineral amendments significantly increased the yields of both root and foliage. The increases in root dry weights were 62.9, 44.8, 52.1, 21.5 and 21.2% for S, PG, AS, PA, and SA, respectively, while the corresponding increases in foliage dry weights were 63.1, 44.6, 51.9, 21.6 and 21.3%, respectively. Thus, the effectiveness of these amendments in increasing the dry weight of both root and foliage can be arranged according to the following sequence: S > PG > PA ≈ SA > control.

Concerning the interactions between the investigated treatments, the highest root and foliage yields were recorded due to the interaction effect between sulfur and compost in the presence of *Azolla* and Cyanobacteria inoculants (14.56 and 5.59 Mg ha^{-1}, respectively). On the other hand, no significant effect was detected due to the triple interactions among the microbial, compost, and the mineral amendments, *i.e.*, phosphoric acid (PA), sulphuric acid (SA), phosphogypsum (PG), aluminum sulfate (AS), sulfur (S).

Table 7. Effect of microbial inoculation (M), compost (C) and the mineral amendments (A) on the dry weight of both root and foliage (Mg ha^{-1}) of sugar beet plant.

Treatment	Root dry weight (Mg ha^{-1})							Foliage dry weight (Mg ha^{-1})						
	Non	S	PG	AS	PA	SA	Mean	Non	S	PG	AS	PA	SA	Mean
Without inoculation														
-C	6.52	10.47	9.69	10.11	8.13	8.29	8.87	2.49	4.01	3.71	3.86	3.11	3.17	3.39
+C	7.56	12.19	10.49	11.02	8.84	8.73	9.81	2.90	4.67	4.01	4.21	3.38	3.34	3.75
Mean	7.04	11.33	10.09	10.57	8.49	8.51	9.34	2.69	4.34	3.86	4.04	3.25	3.25	3.57
With inoculation														
-C	7.20	11.63	10.19	10.65	8.64	8.60	9.49	2.76	4.44	3.89	4.07	3.31	3.29	3.63
+C	8.70	14.58	13.05	13.84	10.83	10.76	11.96	3.33	5.59	4.99	5.29	4.14	4.12	4.58
Mean	7.95	13.11	11.62	12.25	9.74	9.68	10.72	3.05	5.02	4.44	4.68	3.73	3.70	4.10
Means of compost														
-C	6.86	11.05	9.94	10.38	8.39	8.44	9.18	2.63	4.23	3.80	3.96	3.21	3.23	3.51
+C	8.13	13.38	11.77	12.43	9.84	9.75	10.88	3.12	5.13	4.50	4.75	3.76	3.73	4.16
Mean	7.50	12.22	10.86	11.41	9.11	9.09	10.03	2.87	4.68	4.15	4.36	3.49	3.48	3.84
LSD at.05	**M:** 0.30**, C:** 0.08**, MC:** 0.12**, A:** 0.24**, MA:**0.34**, CA:** 0.34, **MCA:**0.49							**M:** 0.01**, C:** 0.03**, MC:**0.04**, A:**0.10, **MA:**0.14, **CA:**0.14**, MCA:**0.20						

-C: without compost; +C: with compost; Non: without application of amendments; S: sulfur; PG: phosphogypsum; AS: aluminum sulfate; PA: phosphoric acid; SA: sulfuric acid

Grain and straw yields of rice (Mg ha^{-1}) as affected by the microbial, organic and mineral amendments

Significant increases occurred in grain (13.0 %) and straw (14.2%) yields of rice (on a dry weight basis) due to the microbial inoculation by *Azolla* and Cyanobacteria extract (Table 8). Likewise, the application of compost significantly increased grain by 8.2% and straw yield by 6.1%. Furthermore, the investigated mineral amendments significantly increased the grain yield by 15.8, 14.0, 9.2, 11.5 and 16.4% due to the application of S, PG, AS, PA and SA, respectively; whereas, the corresponding ones for the straw yield were by 19.3, 15.0, 10.2, 11.9 and 19.9%, respectively. It is worthy to mention that the highest grain and straw yields (on a dry weight basis) were 8.79 and 17.19 Mg ha^{-1}, respectively which were produced owing to the combined application between sulfuric acid and compost in the presence of the microbial inoculants (*Azolla* and Cyanobacteria extract). It seems that the interactions between bioagents + compost and those between compost + mineral amendments were of no significant effect on either seed or straw yield. Likewise, the triple interactions among the microbial, organic and mineral amendments seemed to be insignificant on both seed and straw yields.

Table 8. Effect of microbial inoculation (M), compost (C) and the mineral amendments (A) on the dry weight of both grain and straw (Mg ha^{-1}) of rice plant.

Treatment	Grain dry weight (Mg ha^{-1})							Straw dry weight (Mg ha^{-1})						
	Non	S	PG	AS	PA	SA	Mean	Non	S	PG	AS	PA	SA	Mean
Without inoculation														
-C	5.52	6.40	6.31	6.02	6.17	6.45	6.15	10.52	12.57	12.10	11.60	11.79	12.62	11.87
+C	6.00	6.93	6.83	6.55	6.68	6.98	6.66	11.19	13.33	12.86	12.31	12.50	13.38	12.59
Mean	5.76	6.67	6.57	6.29	6.43	6.71	6.40	10.86	12.95	12.48	11.95	12.14	13.00	12.23
With inoculation														
-C	6.98	8.07	7.93	7.62	7.76	8.12	7.75	13.50	16.12	15.55	14.90	15.12	16.19	15.23
+C	7.55	8.74	8.60	8.24	8.40	8.79	8.38	14.35	17.12	16.50	15.81	16.07	17.19	16.17
Mean	7.26	8.40	8.26	7.93	8.08	8.45	8.07	13.92	16.62	15.02	15.36	15.60	16.69	15.70
Means of compost														
-C	6.25	7.24	7.12	6.82	6.97	7.29	6.95	12.01	14.35	13.82	13.25	13.45	14.40	13.55
+C	6.77	7.83	7.71	7.39	7.54	7.88	7.52	12.77	15.22	14.68	14.06	14.29	15.29	14.38
Mean	6.51	7.54	7.42	7.11	7.26	7.58	7.23	12.39	14.78	14.25	13.65	13.87	14.85	13.97
LSD at 0.05	**M:** 0.01, **C:** 0.07, **MC:** NS, **A:**0.06, **MA:**0.08, **CA:**NS, **MCA:**NS							**M:**0.07, **C:**0.12, **MC:**NS, **A:**0.07, **MA:**0.10, **CA:**NS, **MCA:**NS						

-C: without compost; +C: with compost; Non: without application of amendments; S: sulfur; PG: phosphogypsum; AS: aluminum sulfate; PA: phosphoric acid; SA: sulfuric acid

Discussion

Effect of the bio-agents on ameliorating the saline-sodic soil and improving the plants growth thereon

Amending soils with the bio-extract containing *Azolla* and Cyanobacteria significantly decreased the soil EC_e and ESP. These results agree with those obtained by Eletr *et al.* (2013), who recorded significant reductions in soil salinity (EC_e) and exchangeable sodium percentage (ESP) when the salt-affected soils were inoculated with cyanobacteria. Also, Aref *et al.* (2011) reported significant decreases in the soil salinity with the application of mixed *Azolla* and cyanobacteria extracts to the saline-sodic soils of South of Sahl El-Hossinia Plain. Probably, *Azolla* and cyanobacteria excrete extracellular compounds *e.g.* polysaccharides, peptides, lipids, organic acids that can decrease the soil pH (El-Ayout *et al.*, 2004 and Molnar and Ordog, 2005). Furthermore, these compounds might chelate sorbed Na^+ and therefore decrease the sodicity hazards in soil (Nisha *et al.*, 2017). Thus, root and foliage yields of sugar beet (winter season), as well as the grain and straw yields of rice (summer season), significantly increased due to the microbial inoculation by *Azolla* and Cyanobacteria extract. These results agree with those obtained by Mostafa *et al.* (2013), who revealed that inoculating Sahl El-Hussinia soil (a saline-sodic one) with Cyanobacteria increased significantly the dry weights of both sugar beet root and foliage. Also, Aref *et al.* (2011) reported that application of *Azolla* and Cyanobacterial extracts to the rice field under saline soil conditions led to significant increases in the dry weights of rice grains and straw. These bio-agents can also fix the atmospheric N_2 and therefore improve the growth of the plants (Wagner, 1997). Additionally, *Azolla* and Cyanobacteria produce growth promoting substances like gibberellins, cytokinins, auxins, abscisic acids, vitamins, antibiotics and amino acids that can increase the plant growth and yield of crops and this might, in turn, overcome the adverse effects of salinity on the saline soil (Aref *et al.*, 2009 and Bindhu, 2013). On the other hand, increasing accumulation of free proline in leaves of both sugar beet and rice plants due to the microbial inoculation by *Azolla* and Cyanobacterial extracts compared with nonmicrobial treatments may be due to that *Azolla* and Cyanobacteria as phytohormones increasing the accumulation of osmoprotectant compounds such as proline in these plants, thus the proline maintains the osmotic balance and increases the membrane stability, photosynthetic activity, mineral uptake and antioxidant activity and at the same time, mitigates the harmful effect of Na ion on the cell membrane and consequently enhancing the ability of plants to tolerate salinity stress in such soils. These results are similar to those obtained by Mostafa *et al* (2013), who found an increase in the proline accumulation in the root of sugar beet plants grown in saline-sodic soil at the region of South of El-Hossinia Plain as a result of treatment with Cyanobacteria extract.

Effect of compost on ameliorating the saline-sodic soil and improving the growth of the plants grown thereon

Compost application significantly decreased the soil EC_e and ESP. Similar results were reported by Lakhdar *et al.* (2009), who recorded the positive effect of compost applications to a saline-sodic soil on decreasing the soil salinity and ESP. Also, Abdel-Fattah (2012) went to similar results and reported that the application of organic amendments such as compost significantly decreases the soil ESP compared to control. Probably compost mobilizes soil Ca, thus neutralize the residual sodium carbonate in soil solutions (Choudhary *et al*., 2011).

Compost applications also significantly increased root and foliage yields of sugar beet in addition to its significant effect on increasing the grain and straw yields of rice. It is thought that the compost enrich soils with essential nutrients such as N, P and K (Hanay *et al*., 2004) and, furthermore, stimulates the biological activities in soil, mainly halophilic bacteria, that can colonize sugar beet roots during the early stages of growth (Walker and Bernal, 2008). Moreover, the compost increases soil moisture content (Kamel, 2016) which decrease the soil resistance affecting the growth of sugar beet roots (Mustafa *et al*., 2013). Thus, there is no wonder to find out that compost significantly improved the growth performance of plants under the salt-affected soil conditions (Yan *et al.*, 2015; Kamel *et al*., 2016).

Effect of the mineral amendments on ameliorating the saline-sodic soil and improving the growth of the plants grown thereon

Application of sulfur, phosphogypsum, aluminum sulfate, phosphoric acid and sulfuric acid can effectively decrease the soil EC_e and ESP. Probably, these amendments function on increasing the solubility of the $CaCO_3$ present in the soil. Thus, the released Ca substitute the exchangeable Na on the soil exchange complex, which in turn, decrease the soil EC and correct the soil sodicity (SAR and ESP) (Mc Cauley and Jones, 2005 and Abdelhamid *et al*., 2013). These conclusions are in harmony with those obtained by Cardon and Mortvedt (2001); Mc Cauley and Jones (2005); Gharaibeh *et al.* (2012); Farag *et al.* (2013) and Abd El-Fattah (2014). The superiority of S over the other mineral amendments in decreasing the soil EC_e and ESP might be attributed to its slow oxidation in soil by *Thiobacillus* bacteria (Hilal and Abd-ElFattah, 1987) forming sulfuric acid and therefore enriching soils continuously with soluble Ca^{2+} ions. It is thought that phosphoric acid produces an acidic-homogenous solution which helps increase the dissolution of the $CaCO_3$ present in the soil (Gharaibeh *et al.*, 2010 and 2012). Also, H_2SO_4 increases the solubility of the native $CaCO_3$ in soils to provide Ca^{2+} (Kamel *et al*., 2016); however, these acids can be leached out the soil rhizosphere rapidly. Aluminum sulfate can also solubilize the native $CaCO_3$ in soil (El-Shazly *et al.*, 2014). Concerning phosphogypsum, it is a source of Ca (Fahmi and Abbas, 2012) that can substitute the exchangeable Na and therefore decreases its hazardous effect on the soil.

Application of the investigated mineral amendments also increased the root and foliage yields of sugar beet. These results agree with those of El-Shazly *et al.* (2014), who found that the root yield of sugar beet increased in the saline-sodic soil of Sahl El-Hosinia region when amended with aluminum sulfate. Also, Kamel *et al*. (2016) found that using H_2SO_4 with irrigation water to ameliorate a saline-sodic soil could an effectively increase the yield of sugar beet growth.

The highest increases in yields of sugar beet (root and foliage) and rice (grains and straw) were recorded for soils having a considered percentage of $CaCO_3$ and amended with S. This may indicate that sulfur can ameliorate the adverse effects of salinity on plants through facilitating higher K^+/Na^+ selectivity (Hasegawa *et al.,* 2000), in addition, it helps plant growth through osmotic adjustment into its cell (Ibrahim and Naz, 2014) by increasing accumulation of suitable organic solutes (Girija *et al.*, 2002). Furthermore, S protects the plant against salinity stress by stabilizing cell membranes and reducing the oxidative damage by reactive oxygen species (ROS) (Larkindale and Knight, 2002). Also, sulfur is an important nutrient for the plant growth and development where it enters in the composition of many important compounds such as glutathione, vitamins, co-enzymes, phytohormones. (Hasegawa *et al.*, 2000). Concerning phosphogypsum, it is also considered a good source of nutrients (P, S and Ca) (Keren and Shinberg, 1981 and Fahmi and Abbas, 2012) that improves plant growth and increases the tolerance of the grown plants to soil salinity (Gharaibeh *et al.,* 2012). Also, Ca recovers the membrane integrity and selectivity (Grattan and Grieve, 1998). Similar results were recorded by Helmy *et al.* (2013) who found that using the elemental sulfur and sulfuric acid for the amelioration of a saline-sodic soil (EC_e = 14.8 dSm^{-1} and ESP = 24.6) resulted in significant increases in yield of rice grain and straw compared with the control.

It seems that the values of soil EC and ESP in the summer growing season were significantly higher than those occurred in the winter growing one. These results may be attributed to the secondary salinization effect due to the high salinity and the higher quantity of the applied irrigation water on one hand and the increase in the soil water table level upon the cultivation of rice on the other hand. This finding is in agreement with that obtained by Wahdan (2009), who revealed that continuous usage of either saline drainage water directly or mixed with the Nile water build up salts in the irrigated soils. Furthermore, it is thought that the Egyptian climate is characterized by a hot dry summer (temperature ranges between 38 to 43 ^{0}C) (FAO, 2016), with relatively higher rates of water evaporation from soils during summer seasons (Negm, 2017). Accordingly, salts arose by the capillary action in the summer where it evaporates on the soil surface leaving salts; hence soil salinity increases in the summer than in the winter.

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مدى جدوى استخدام المحسنات الميكروبية والعضوية والمعدنية لإصلاح الأرض الملحية–الصودية وتداعياتها على إنتاجية بنجر السكر والأرز النامين عليها

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تهدف الدراسة الحالية إلى تقييم جدوى تحسين الأرض الملحية–الصودية (ملوحة التربة = 12.38 ديسيسيمنز/م، نسبة الصوديوم المتبادل = 23.38، محتوى كربونات الكالسيوم = 25.44 جم/كجم تربة)، بإضافة بعض المحسنات الحيوية (مستخلص الأزولا والسيانوبكتريا بنسبة 1:1) ، العضوية (كمبوست) والمعدنية (الكبريت العنصرى ، حامض كبريتيك مخفف ، حامض فوسفوريك مخفف ، فوسفوجبس وكبريتات الألومنيوم أو الشبه) إما منفردة فحسب أو في تداخلات لتحسين بعض خواص هذه التربة. لذلك أجريت الدراسة تحت الظروف الحقلية بقرية الرواد جنوب سهل الحسينية شمال شرق دلتا النيل بمحافظة الشرقية بمصر لموسمين متتاليين: موسم شتوي (2015–2016) تحت زراعة بنجر السكر وموسم صيفي (2016) تحت زراعة محصول الأرز. تم ري التربة محل الدراسة بمياه منخفضة الجودة (التوصيل الكهربى 1.58±0.06) و نسبة الصوديوم المدمصة (7.51±13.0). تم استخدام مستخلص الأزولا والسيانوبكتريا (1:1) بمعدل 50 لتر/هكتار. كما تم استخدام الكمبوست بمعدل 9.02 طن/هكتار وكان ذلك فقط قبل زراعة محصول بنجر السكر. وقد تمت إضافة حامض الكبريتيك وحامض الفوسفوريك فى صورة مخففة من خلال مياه الرى.

وقد دلت النتائج المتحصل عليها على أن:

1. خفضت معنوياً إضافة كل من المحسنات الميكروبية والعضوية والمعدنية المدروسة بعض خصائص التربة الكيميائية من ملوحة ونسبة الصوديوم المتبادل خلال كل من موسمى الدراسة، وعلاوة على ذلك تحسن بشكل معنوى إنتاجية محاصيل كل من بنجر السكر (الدرنات والعرش) والأرز (الحبوب والقش). وكانت التداخلات بين هذه المعاملات أيضاً ذات تأثير معنوى على جميع الخواص تحت الدراسة من تربة ونباتات منزرعة.
2. كان التداخل المشترك بين معاملة الكبريت + الكمبوست + التلقيح الميكروبى بمستخلص الأزولا والسيانوبكتريا هو الأكثر فعالية لتحسين الخصائص الكيميائية للتربة (التوصيل الكهربى ونسبة الصوديوم المتبادل) بالإضافة إلى إنتاجية محصول النباتات المنزرعة على هذه التربة. حيث انخفضت ملوحة التربة إلى1.22 ± 7.88 ديسيسيمنز/م بينما وصلت قيم نسبة الصوديوم المتبادل إلى 0.25 ± 7.36.
3. كانت إنتاجية الدرنات والعرش لبنجر السكر هى 13.38 و 5.13 طن/هكتار، على التوالى على أساس الوزن الجاف فى حين كانت إنتاجية حبوب وقش الأرز هى 7.24 و 14.34 طن/هكتار، على التوالى.
4. بناءاً على ما سبق، فإنه يمكن أن يوصى باستخدام الإضافات الثلاثية من الكبريت + الكمبوست + التلقيح الميكروبى بمستخلص الأزولا والسيانوبكتريا لتحسين بعض خصائص الأرض الملحية–الصودية والمروية بمياه ذات جودة منخفضة (مياه خلط بنسبة 1:1 صرف زراعى + مياه النيل) من ناحية وللحصول على أفضل غلة محصولية من ناحية أخرى.