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Integrated Approaches towards Ameliorating A Saline Sodic Soil and Increasing The Dry Weight of Barley Plants Grown Thereon

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SOIL salinization and water scarcity are among the major threats affecting crop productivity in Egypt. To ameliorate a saline-sodic soil (EC= 8.2 dS m^{-1} and ESP= 22.9%) under no-leaching conditions, a greenhouse experiment was conducted, including three factors (1: *Arthrospira platensis* bio-inoculant with two treatments (non-inoculated and inoculated seeds), 2: phosphogypsum with three rates (non, 50% and 100 of the gypsum requirements and 3: compost with three rates (none, 7.5 and 15 g kg^{-1}) to evaluate their efficiencies on increasing barley plants grown on such a soil, on one hand, and minimizing soil deterioration in terms of soil EC and ESP., on the other hand. After 75 days of incubation, *Arthrospira platensis* increased significantly soil EC values, while decreased soil ESP. This inoculant also increased P and K uptake by plants while recorded no significant effect on barley dry weight. For soils treated with either compost or phosphogypsum, their highest rates decreased significantly soil ESP and, at the same time, caused significant increases in barley dry weights. Furthermore, these two amendments increased significantly NPK availability ; consequently, their uptake by plants. Generally, phosphogypsum seemed to be more efficient in minimizing the negative implications of no leaching conditions on chemical characteristics than did the compost treatment investigated. Combined amendments seemed to be more efficient than the single ones on improving soil characteristics and increasing plants grown thereon, especially the triple applications which reduced soil ESP by more than 50%, while increased barley dry-weight by approximately 40%. In conclusion,the integrated treatments are recommended to raise barley productivity grown on salt affected-soils under no leaching conditions; while lessen further soil degradation.

Keywords: Saline-sodic soil, *Arthrospira platensis*, Phosphogypsum; Compost; Barley plants.

Introduction

Salinization is one of the major threats of soil sustainability in the world (Masoud et al., 2019), especially in arid and semi-arid areas (Rousk et al., 2011; Abou Samra, and Ali, 2018; Mahdavi and Fujimaki, 2019). In Egypt, the stressed conditions of soil salinization has grown up (El-Ramady et al., 2019a; El-Akhdar et al., 2019; Negm et al. 2019) to represent about 46% of the total Nile Delta zone (El-Ramady et al., 2019b). This situation is associated with water scarcity problems (Ouda and Zohry, 2020). Thus, the main challenge of the Egyptian farmers is to grow up salt-tolerant plants under such saline and alkaline conditions and also to manage the ameliorating inputs to lessen further soil deterioration while sustaining soil productivity. It is thought that application of gypsum might not be the optimum choice to ameliorate saline-sodic soils without considering suitable amounts of water to leach out salts away from the rhizosphere (Wang et al., 2019). Also, organic amendments may retain salts against leaching; hence, increase salt stress conditions in soils (Wang et al., 2019). Accordingly, four integrated strategies were tested, in this study, for ameliorating a saline sodic soil without considering irrigation

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requirements. The first one is based on the dual application of phosphogypsum and compost. In this concern, calcium (in phosphogypsum) is a low-cost amendment (Makoi and Verplancke, 2010) that can substitute exchangeable sodium; hence reduce the sodicity hazards in soil (Cao et al., 2019). Moreover, phosphogypsum is highly solule in water and its physiological effect is acidic (Elloumi et al., 2015) and this probably makes phosphogypsum more effective than ordinary gypsum in ameliorating saline-sodic soils (Abd El-Fattah, 2014). On the other hand, application of organic amendments is thought to encourage the downward movement of Na-salts away from the rhizosphere (Li et al., 2019a) while, excess calcium salts might prefer to bind to the carboxylic groups of the organic amendment (Adusei-Gyamfi et al., 2019). This may; in turn, decrease both soil EC and ESP, while improves the release of some nutritive elements upon this organic amendment decomposition (El-Naqm etal.,2019); consequently increases plant grown thereon (Amer et al., 2020). Another integrated amelioration technique is through amending the saline-sodic soil with phosphogypsum +cyanobacteria. According to this approach, soil sodicity is reduced with the application of phosphogypsum, while the bio-inoculants can improve the growth of plants under biotic stresses probably through increasing the uptake of soil K (Selem, 2019). Moreover, cyanobacteria may fix atmospheric N (Murukesan et al., 2019) and; therefore, increase its uptake by plants (Shahane et al., 2019). This combination can probably decrease sodicity (ESP) with slight or no significant effect on soil EC. Also, it can increase NPK uptakes as well as the biomass of the grown plants. Combination between the organic amendments and cyanobacteria is the third tested integrated strategy that can be applied for the remediation of saline-sodic soils. According to this combination, cyanobacteria can degrade this amendment to get its needs of carbon (Fuchsman et al., 2019). Therefore this dual application can probably increase the efficiency of each other in ameliorating salt-affected soils by decreasing soil EC and ESP, increasing the availability of NPK and their uptakes by plants with a positive effect on the plant growth. We believe that the combination among cyanobacteria, organic residues and phosphogypsum may have a further superior effect than the single amendments did on decreasing soil EC and ESP while increasing the availability and uptake of NPK by barley plants; thus increase their growths. This study aims to investigate the potentiality of using *Arthrospira platensis* (cyanobacteria), compost and phosphogypsum either solely or in combinations under no leaching conditions to increase the productivity of salt-affected soils on one hand and lessen further soil deterioration in terms of soil EC and ESP on the other hand.

Materials and Methods

Materials of study

Surface soil samples (0-30 cm) were collected from Sahl El-Hussainia, Sharqia Governorate, Egypt. These samples were analyzed for their physical and chemical characteristics as outlined by Klute (1986) and Sparks et al. (1996). Selected physicochemical characteristics of the investigated soil are presented in Table 1.

TABLE 1. Physicochemical characteristics of the investigated soil

Soil physical characteristic						
	Particle size distribution %				**Textural class**	**Field capacity,%**
Parameter	**Coarse sand**	**Fine sand**	**Silt**	**Clay**		
Value	4.18	29.72	16.83	49.28	Clay	59.82
Soil chemical characteristic						
Parameter	EC*, dS m^{-1}	pH**	OM, g kg^{-1}	$CaCO_3$, g kg^{-1}	CEC, $cmol_c$ kg^{-1}	ESP
Value	8.20	7.75	5.10	5.10	45.37	22.90

EC*: determined in soil paste extract; pH** determined in soil:water suspension prepared at a rate of 1:2.5; OM: organic matter content in soil; CEC: cation exchange capacity

Cyanobacteria (*Arthrospira platensis* HSSASE5, version KT277788) was obtained from Soil, Water & Environment Research Institute, Giza (Egypt). Seeds of barley (*Hordeum vulgare* L., Giza 132) were obtained from the National Research Centre, Egypt. Half weight of barley was mixed thoroughly for thirty minutes with the *Arthrospira platensis* suspension before the cultivation process, while the second half was left without inoculation. Phosphogypsum (88% purity) was obtained from El-Araby Company (Egypt). Compost was kindly obtained from the Faculty of Agriculture (Benha University) and it was characterized with pH, EC, moisture, bulk density, organic carbon, C/N ratio, Total P and Total K of 7.42, 6.92 dS m^{-1}, 11.37%, 0.64 g cm^{-3}, 42.86 g kg^{-1}, 12.76/1, 0.80 g kg^{-1} and 10.38 g kg^{-1}, respectively. pH and EC were determined in 1:5 (compost: water) suspension.

The greenhouse experiment

The experiment contained eighteen treatments in triplicates resulted from the different combinations of *Arthrospira platensis*, phosphogypsum and compost. These treatments were inoculation with *Arthrospira platensis* at two rates (0= *-B* and inoculated= *+B*), phosphogypsum at three rates [9 g kg^{-1} (equivalent to 100% of the phosphogypsum requirements = G_{100}), 4.5 g kg^{-1} (equivalent to 50% of the phosphogypsum requirements = G_{50}) and 0 g kg^{-1} = G_0 (the non-amended control treatment)] and compost at three different rates (0, 7.5 and 15 g kg^{-1} (based on recommendations of previous researches).

Soil samples were mixed thoroughly with the abovementioned amendments then packed in plastic pots (20 cm diameter × 17.5 cm depth). The experimental pots were filled further 3 kg soil. These pots were arranged in a complete randomized design under the greenhouse conditions. Some pots were cultivated with inoculated seeds (10 seeds per pot), while other pots were cultivated with barley seeds without *Arthrospira platensis* inoculation. All pots received NPK fertilizers at the recommended rates of the Egyptian Ministry of Agriculture (equivalent to 100 kg N,40 kg P and 60kg K ha^{-1} in the forms of the following fertilizers: urea, calcium superphosphate and potassium sulphate, respectively). Plants were irrigated with tab water every 5 days to bring and maintain soil moisture at 80% of its water holding capacity. After germination, plants were thinned to five plants per pot and all pots were kept under greenhouse conditions for 75 days. Afterwards, the aerial parts of the grown plants were cut and dried at 60-70 °C for 72 h. Also, soil samples were collected from the rhizosphere of the grown plants.

Plant and soil analyses

Dried plant materials were cut, crushed and equivalent masses of 0.5 g were digested in a mixture of H_2SO_4 and H_2O_2 (1:1) as outlined by Lowther (1980) then transferred volumetrically using deionized water to 50 mL conical flasks. Total contents of NPK were measured according to the protocol of Page et al. (1982); total-N by micro-Kjeldahel apparatus, total-P spectrophotometrically (SM1600 UV-VIS Spectrophotometer) and total K and Na by flame photometer (Jenway model PFP7 flame photometer). Soil pH was measured in 1:2.5 (soil: water) suspension by pH meter (JENCO 6173). Soil EC was determined in the soil paste extract using EC meter (HANNA EC 215). Available amounts NPK were also determined in soil samples according to Page et al. (1982) *i.e.,* available soil-N was extracted by K_2SO_4, then measured by micro Kjelkdahel unit, Olson-extracted-P was determined using Spectrophotometer and ammonium acetate (1*N*, pH 7) extracted-K was measured by flame photometer.

Data analysis

The obtained data were statistically analyzed using PASW Statistics software through the analysis of variance (ANOVA) and Dunken or Tests at 0.05 probability level. The figures were presented using Sigma Plot 10.0.

Results

Effect of soil amendments on soil EC and ESP

Table 2 indicated that inoculating barley seeds with *Arthrospira platensis* significantly increased soil EC. Such an unexpected result was detected in soils that did not receive any amendment as well as those received zero or 7.5 g compost kg^{-1} soil. However, in the soil amended with 15 g compost kg^{-1} and inoculated with this bio-agent, no significant variations in the measured values of soil EC were noticed. In the case of phosphogypsum, its application at a rate of 9 g kg^{-1} had no significant effect on soil EC. However, its application at the recommended rate (9 g kg^{-1}) significantly decreased soil EC.

Inoculating barley seeds with *Arthrospira platensis* markedly decreased soil ESP (Table 2). Likewise, amending soil with either phosphogypsum or compost significantly diminished soil ESP. Such reductions seemed to be more significant with increasing rates of these amendments in soil. Concerning the combination among the studied treatments, it seemed that the highest reduction in soil ESP was attained due to the dual application of 9 g phosphogypsum +15 g compost kg^{-1} (in presence of *Arthrospira platensis* inoculum). This treatment decreased soil ESP by more than 50% of its initial value. On the other hand, the recorded ESP value in soil amended with 15 g compost kg^{-1} was lower than the corresponding one recorded in soil amended with 7.5 g compost kg^{-1} in presence of both *Arthrospira platensis* inoculums and either of 0 or 4.5 g kg^{-1} phosphogypsum.

Effect of soil amendments on barley dry weight

Inoculating plants with *Arthrospira platensis* and application of 7.5 g compost kg^{-1} had no significant effect on barley dry weight (Fig 1). However, significant increases occurred in plant dry weight owing to application of the organic compost at a rate of 15 g kg^{-1}. In soils amended with phosphogypsum, significant increases in plant dry weights were also noticed, especially with increasing rate of application of this amendment. Generally, phosphogypsum application seemed to be more efficient in minimizing the implications of soil no leaching conditions on salinity and sodicity than did the compost addition. The combination between the investigated three factors (bio× organic× chemical) revealed that the highest increases in plant dry weight were achieved in soils amended with 9 g phosphogypsum” irrespective of either the rate of applied compost or inoculation with *Arthrospira platensis*.

TABLE 2. Soil EC and soil ESP (mean±SD) as affected by amending a saline-sodic soil with Arthrospira platensis, compost and phosphogypsum either solely or in combinations

Compost (C)	Bio-treat (B)	Phosphogypsum, g kg^{-1} (G)				Phosphogypsum, g kg^{-1} (G)			
		0	4.5	9	**mean**	0	4.5	9	**mean**
		Soil EC (dS m^{-1})				Soil ESP			
0 g kg^{-1}	*-Bio*	8.90±0.56	6.85±0.43	6.74±0.61	**7.50**	18.35±1.64	11.21±0.93	10.03±0.95	**13.20**
	+Bio	9.19±0.73	9.79±0.33	9.00±0.72	**9.33**	16.76±0.55	9.43±0.73	7.10±0.63	**11.09**
	mean	**9.05**	**8.32**	**7.87**	8.41	**17.55**	**10.32**	**8.56**	12.14
7.5 g kg^{-1}	*-Bio*	6.24±0.56	7.61±0.45	6.34±0.53	**6.73**	11.73±1.10	12.84±0.89	12.74±0.69	**12.44**
	+Bio	9.04±0.83	9.73±0.71	9.17±0.84	**9.31**	9.36±0.78	10.26±0.93	11.97±0.89	**10.53**
	mean	**7.64**	**8.67**	**7.76**	8.01	**10.54**	**11.55**	**12.36**	11.81
15 g kg^{-1}	*-Bio*	8.52±0.77	9.70±0.82	10.38±1.04	**9.53**	11.64±0.94	11.97±0.92	9.59±0.84	**11.07**
	+Bio	9.71±0.94	8.90±0.82	8.89±0.78	**9.20**	10.94±0.82	11.24±0.98	9.01±0.60	**10.39**
	mean	**9.12**	**9.3**	**9.64**	9.34	**11.29**	**11.61**	**9.30**	10.72
Grand mean		8.60	8.76	8.42		13.13	11.16	10.07	
Means of Compost									
	-Bio	7.89	8.05	7.82	7.92	13.91	12.01	10.79	12.23
	+Bio	9.31	9.47	9.02	9.27	12.35	10.31	9.36	10.67
LSD $_{(0.05)}$		C=0.84, B=0.69, G=ns, C×B=1.19, B×G= ns,C×G=ns, C×B×G=2.06				C=0.40, B=0.32, G=0.40, C×B=0.56, B×G= ns, C×G=0.69, C×B×G=0.97			

-*B*: without inoculation, +*B*: with inoculation.

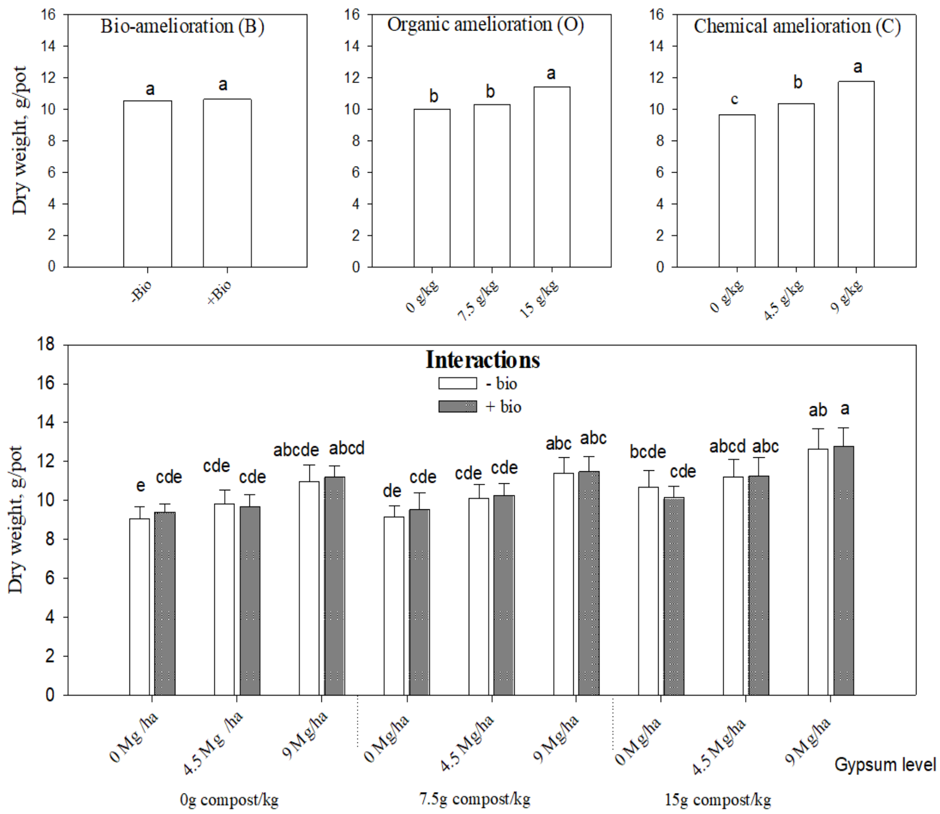

Fig. 1. Barley dry weight (mean±SD) as affected by amending a saline-sodic soil with Arthrospira platensis, compost and phosphogypsum either solely or in combinations. Similar letters indicate no significant variations.

Effect of soil amendments on nutrient uptake by barley plants

N- uptake

Soaking seeds in *Arthrospira platensis* suspension recorded no momentous effect on N-uptake by plants. However, amending the investigated soil with compost significantly improved N uptake (Table 3). Such increases were more pronounced with increasing the rate of applied compost. Likewise, amending the investigated soil with phosphogypsum increased significantly N-uptake by plants. Interactions among these three factors were also of significant effect on barley dry weight. In this concern, the highest increases in N-uptake were achieved due to amending soil with both "15 g compost + 9 g phosphogypsum kg^{-1}" where these increases were 3-4 folds higher than the non-amended control treatment.

P-uptake

Marked increases in P-uptake also occurred in plants inoculated with *Arthrospira platensis* (Table 3). Likewise, increasing the rate of applied compost or phosphogypsum resulted in concurrent significant increases in P-uptake by barley plants. Generally, the highest uptake of P occurred by the plants inoculated with *Arthrospira platensis* and amended with either "15 g compost + 9 g phosphogypsum kg^{-1}" or " 15 g compost + 4.5g phosphogypsum kg^{-1}" with no significant variations between these two treatments.

K-uptake

Important rises occurred in K-uptake by barley plants owing to soaking its seeds in *Arthrospira platensis* suspension. Likewise, amending soil with the organic amendment (compost) increased significantly the uptake of K by plants. Such increases were more pronounced with increasing the rate of applied compost. Although, the application of 4.5 g phosphogypsum kg^{-1} increased significantly the uptake of K by plants; however, increasing the dose of its application (*i.e.,* 9 g kg^{-1}) reduced significantly this uptake. The attained values of K-uptake by barley plants at this level of phosphogypsum were still significantly higher than that attained for the control treatment.

TABLE 3. NPK-uptake (mean+SD) by barley plants grown on a saline-sodic soil as affected by Arthrospira platensis, compost and phosphogypsum either solely or in combinations

Compost (C)	Bio-treat (B)	Phosphogypsum, g kg^{-1} (G)											
		0	4.5	9	mean	0	4.5	9	mean	0	4.5	9	mean
		N-uptake, g pot^{-1}`				P-concentration, g pot^{-1}				K-concentration, g pot^{-1}			
0 g kg^{-1} (C0)	*-Bio*	201.4±16.4	376.5±24.4	355.1±29.4	**310.99**	1.9±0.17	3.0±0.2	5.00±4.2	**3.30**	121.40±9.7	152.6±14.3	199.5±15.5	**157.79**
	+Bio	282.4±24.3	349.4±28.4	382.9±28.4	**338.25**	3.3±0.31	3.5±0.3	4.9±3.8	**3.91**	135.4±10.2	200.7±16.5	152.2±12.8	**162.76**
	mean	**241.9**	**362.94**	**369.01**	324.62	**2.58**	**3.28**	**4.97**	3.61	**128.39**	**176.63**	**175.81**	160.26
7.5 g kg^{-1} (C1)	*-Bio*	325.2±27.4	338.3±30.2	345.1±29.3	**336.20**	2.2±0.1	3.2±0.2	5.1±0.4	**3.50**	138.1±9.7	189.1±15.3	168.4±14.3	**165.21**
	+Bio	276.3±21.4	317.8±27.4	363.1±28.4	**319.10**	4.5±0.3	6.3±0.6	7.4±0.6	**6.05**	187.0±14.3	220.0±19.4	186.2±15.4	**197.74**
	mean	**300.8**	**328.08**	**354.11**	327.65	**3.34**	**4.76**	**6.21**	4.77	**162.50**	**204.55**	**177.31**	181.47
15 g kg^{-1} (C2)	*-Bio*	287.4±25.6	365.4±30.4	450.5±41.4	**367.76**	3.3±0.4	3.7±0.3	4.6±0.4	**3.85**	146.9±12.4	202.3±18.4	205.3±18.4	**184.84**
	+Bio	299.4±26.4	317.8±28.4	499.1±38.4	**372.13**	4.7±0.4	7.8±0.6	8.4±0.7	**6.97**	175.1±13.6	287.9±22.5	192.8±17.4	**218.50**
	mean	**293.40**	**341.64**	**474.79**	369.94	**3.99**	**5.77**	**6.48**	5.41	**161.00**	**245.11**	**199.05**	201.71
Grand mean		278.69	344.22	399.30		3.30	4.60	5.89		150.65	208.76	184.05	
Means of Compost													
	-Bio	271.32	360.08	383.55	338.32	2.45	3.33	4.88	3.55	135.47	181.31	191.06	169.28
	+Bio	286.07	328.35	415.06	343.16	4.15	5.88	6.90	5.65	165.84	236.21	177.04	193.03
LSD $_{(0.05)}$		C=ns, B=9.4, C=11.6, C×B=16.4, B×G= 16.4,C×G=20.0, C×B×G=28.3				C=1.7, B=1.4, 1.6, C×B=2.4, B×G= 2.4, C×G=2.9, C×B×G=4.1				C=6.3, B=5.1, C=6.3, C×B=8.9, B×G= 8.9,C×G=10.8, C×B×G=15.3			

Na-uptake by barley plants

Figure 2 indicated that soaking seeds with *Arthrospira platensis* significantly decreased Na-uptake by more than 22%. Likewise, amending the studied soil with phosphogypsum, decreased significantly the uptake of Na by plants. On the other hand, application of compost significantly increased the uptake of Na by barley plants. Generally, the highest reductions in Na-uptake by barley plants took place when inoculated plants grown on soils amended with 9 g phosphogypsum +0 g compost kg^{-1} (> 33% reduction in Na uptake when compared with the non-amended control treatment).

Effect of soil amendments on NPK availability in soil

Table 4 indicates that P and K availability in soil markedly enhanced owing to plant inoculation with *Arthrospira platensis*; while this inoculant recorded no significant effect on soil available-N content. Application of compost also showed positive effects on NPK availability in the soil, especially with increasing the rate of applied compost.

Moreover, the application of phosphogypsum resulted in additional substantial rises in NPK availability in the soil, especially with increasing its level of application. In this concern, soaking seeds in *Arthrospira platensis* suspension in the presence of both 9 g phosphogypsum + 15g compost kg^{-1} recorded approximately 1.5 folds higher available-N than the control. Also, this treatment caused 2.35 and 1.3 folds higher than the non-inoculated and non-amended soils for both available P and K contents, respectively.

Biomass of barley as affected by soil EC, ESP and nutrients availability and uptake

To investigate such relationships, multiple correlations were conducted and the obtained results are presented in Table 5. These results indicated that barley biomass was correlated significantly and positively with NPK-uptake by plants. Such uptakes correlated significantly with the available indices of these nutrients in soil. On the other hand, plant biomass significantly and negatively influenced by Na-uptake; however, correlated positively and significantly with soil salinity. This might indicate that barley is more sensitive to Na than its response to soil salinity. Although, *Arthrospira platensis* and phosphogypsum were used to ameliorate such a soil; however, these amendments might raise; on the other hand, soil salinity. In spite of that, these two conditioners improved soil physical conditions and; hence, decreased soil ESP. Thus, a significant positive correlation was detected between barley biomass and soil salinity.

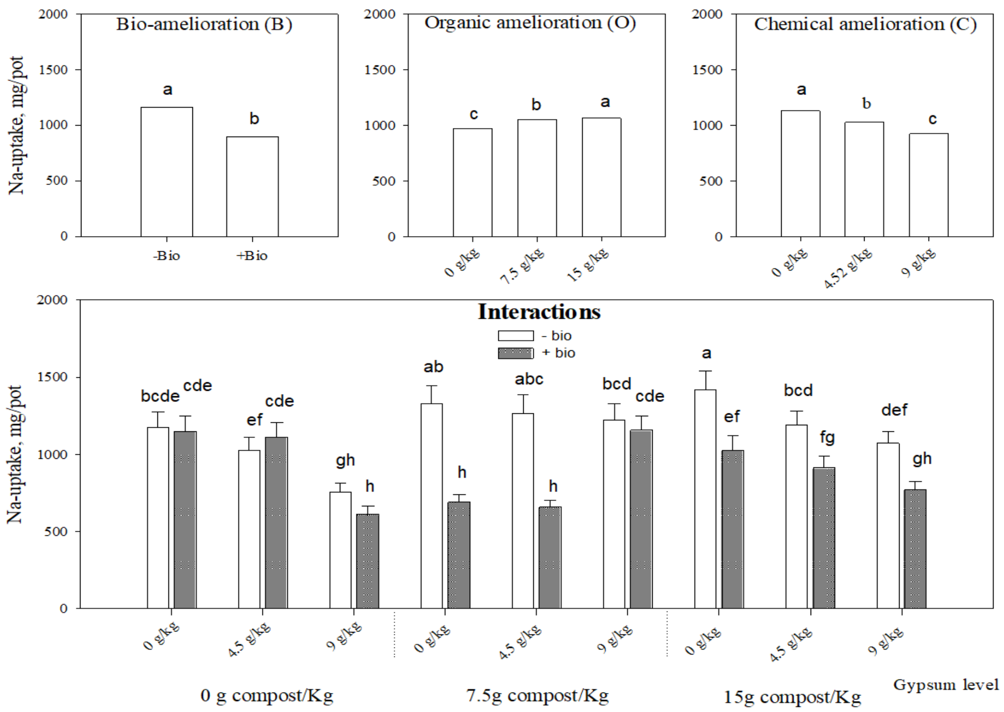

Fig. 2. Na-uptake (mean+SD) by barley plants as affected by Arthrospira platensis, compost and phosphogypsum either solely or in combinations. Mean with the same letter within columns are not significantly different at P = 0.05

TABLE4. Available contents of NPK- (mean±SD) in the saline-sodic soil as affected by inoculating barley seeds with cyanobacteria or amending soils with either compost or phosphogypsum either solely or in combinations

Compost (C)	Bio-treat (B)	Phosphogypsum, g kg^{-1} (G)											
		0	**4.5**	**9**	mean	**0**	**4.5**	**9**	mean	**0**	**4.5**	**9**	mean
		N-availability, mg kg^{-1}				P-availability, mg kg^{-1}				K-availability, mg kg^{-1}			
0 g kg^{-1} (C0)	*-Bio*	112±9	252±18	280±23	**215**	11.31±0.92	23.66±1.32	35.49±2.95	**23.49**	511.56±43.2	678.72±53.2	511.56±41.6	**567.28**
	+Bio	112±8	287±21	322±28	**240**	11.83±0.89	32.69±1.83	39.66±2.87	**28.06**	494.86±31.0	505.49±44.2	672.33±52.7	**557.56**
	mean	**112**	**269**	**301**	228	**11.57**	**28.18**	**37.575**	25.77	**503.21**	**592.11**	**591.95**	562.42
7.5 g kg^{-1} (C1)	*-Bio*	126±9	336±26	427±38	**296**	11.52±0.93	31.2±2.3	44.52±3.50	**29.08**	472.09±33.6	693.34±61.3	686.95±53.0	**617.46**
	+Bio	266±20	287±21	364±28	**306**	11.95±0.75	35.49±2.8	47.32±3.81	**31.59**	715.26±57.7	723.49±61.4	696.99±59.3	**711.91**
	mean	**196**	**312**	**396**	301	**11.74**	**33.35**	**45.92**	30.33	**593.68**	**708.42**	**691.97**	664.69
15 g kg^{-1} (C2)	*-Bio*	147±12	378±33	455±38	**327**	11.83±0.86	48.12±3.12	47.72±3.1	**35.89**	688.95±59.3	711.61±	677.76±61.3	**692.77**
	+Bio	242±17	287±21	434±39	**321**	23.66±1.83	82.81±5.3	59.15±3.9	**55.21**	749.06±63.4	760.02±69.3	714.35±69.3	**741.14**
	mean	**195**	**333**	**445**	324	**17.75**	**65.47**	**53.44**	45.55	**719.01**	**735.82**	**696.06**	716.96
Grand mean		168	305	380		13.68	42.33	45.64		605.30	678.78	659.99	
Means of Compost													
	-Bio	128	322	387	279	11.55	34.33	42.58	29.49	557.53	694.56	625.42	625.84
	+Bio	207	287	373	289	15.81	50.33	48.71	38.28	653.06	663.00	694.56	670.21
LSD $_{(0.05)}$		C=10.2, B=ns, G=10.2, C×B=14.5, B×G= 14.5, C×G=17.7, C×B×G=25.1				C=1.05, B=0.86, C=1.05, C×B=1.49, B×G= 1.49, C×G=1.82, C×B×G=2.57				C=22.1, B=18.1, G=22.1, C×B=31.3, B×G= 31.3,C×G=38.4, C×B×G=54.2			

TABLE 5. Correlation relationships between soil chemical characteristics and plants grown thereon.

		EC	ESP	Plant biomass N-uptake	Plant uptake: P-uptake	Plant uptake: K-uptake	Plant uptake: Na-uptake	Nutrient availability: Av-N	Nutrient availability: Av-P	Nutrient availability: Av-K
	EC									
	ESP	-0.064								
	yield	0.327*	-0.471**							
Plant uptake	N-uptake	0.103	-0.570**	0.831**						
	P-uptake	0.260	-0.425**	0.481**	0.510**					
	K-uptake	0.336*	-0.379**	0.324*	0.333*	0.677**				
	Na-uptake	-0.169	0.584**	-0.184	-0.206	-0.501**	-0.321*			
Nutrient availability	Av-N	0.187	-0.503**	0.767**	0.777**	0.596**	0.528**	-0.247		
	Av-P	0.149	-0.311*	0.438**	0.529**	0.828**	0.796**	-0.259	0.632*	
	Av-K	0.190	-0.156	0.735**	0.337*	0.540**	0.379**	0.019	0.316*	0.434**

*P<0.05 ** P<0.01

Discussion

Soil salinization is one of the major problems in Egypt which accounts for 46% of the total Nile Delta zone. This situation is associated with water scarcity problem and poor agricultural practices. Under such conditions, the capillary rise of water and salts occur (Chávez-García and Siebe, 2019) and consequently salts accumulate on soil surfaces forming salt affected soils. These soils should; therefore, undergo appropriate amelioration in order to minimize their negative consequences on food security (Panda and Parida, 2019). Accordingly, three integrated amelioration techniques *i.e.,* bio-, organo- and chemical were used to ameliorate a saline-sodic soil (EC=8.2 dSm^{-1} and ESP= 22.90), either solely or in combinations in absence of leaching requirements. The mode of action of the investigated amendments will be presented below. It is thought that soil salinization causes nutrient imbalance in plants (Kaya et al., 2001 and Munns and Tester, 2008). Thus, the availability and uptake of NPK by grown plants were also considered in the current study; in addition to Na-uptake which was a matter of concern herein.

Arthrospira platensis (cyanobacteria) for reclamation of saline-sodic soil

Results indicate that soil EC increased significantly when seeds of barley were inoculated with *Arthrospira platensis* before cultivation in soil and amended with either zero or 7.5 g compost kg^{-1}. However, in presence of 15 g compost kg^{-1}, soil EC did not vary significantly between the inoculated and non-inoculated treatments. The following two parallel scenarios might take place in soil: (1) this halophytic organism preserves some salts in the rhizosphere to maintain its activity (mechanism I). The findings of Apte and Thomas (1997) support this assumption as they found that the removal of surface top soil (rich in cyanoacteria) reduced significantly soil EC by approximately 26-38%. Thus, it can be deduced that "the elevated salinity levels might be an obligate to this symbiotic association" (Green et al., 2017). The another scenario indicates that application of organic matter, particularly at its highest rate, stimulated the activities of cyanobacteria enzymes (Jha et al., 2004) which could absorb Na^{+} as an essential nutrient and cannot be replaced by other nutrients (Thomas et al., 1984) (mechanism II). Moreover, cyanobacteria improve additionally soil aggregation and stability (Nisha et al., 2018) besides encouraging further aggregation of soil particles through precipitation of organic matter from cyanobacteria (Singh et al., 2016a; Singh and Singh, 2018). These aggregates might consecutively increase the downward movement of salts from the rhizosphere (mechanism III), especially Na salts (Li et al., 2019b). The results of study did not contradict, therefore, the findings of Eletr et al. (2013) who indicated that cyanobacteria decreased significantly soil EC. This is because the initial soil EC in their study was relatively high (about 11 dS m^{-1}) while this bio-agent probably retained relatively lower concentrations of soluble salts within its rhizosphere.

Soaking seeds in *Arthrospira platensis* suspension also decreased significantly soil ESP. The following mechanisms might also take place owing to seeds coating with *Arthrospira platensis*: (1) the organic acids released by this microbe decreased soil pH (Pandey et al., 2005); hence, increased the solubility of less-soluble Ca-salts in soil (Kamel et al., 2016), (2) cyanobacteria released extracellular polysaccharides that chelated cations e.g. calcium (Nisha et al., 2018); hence, increased its capability to substitute sorbed Na on clay minerals, (3) cyanobacteria produce "specific fatty acids, sucrose- and osmotic-stress-induced proteins" (Singh and Dhar, 2010). These mechanisms may integrate to improve soil aggregation and increase the infiltration of leaching water (carrying out soluble Na) away from the rhizosphere (Anand et al., 2015).

Inoculating plants with cyanobacteria is a widely used practice to increase plant tolerance against salinity stresses because this symbiotic bacterium (Wein et al., 2019) produces antioxidative enzymes (Tang et al., 2007) that can survive under extreme conditions and; therefore, can be used for reclaiming saline-sodic soils (Singh and Dhar, 2010). However, results obtained herein, did not support the effectiveness of the sole application of cyanobacteria for improving the dry weight of barley plants grown on such a saline-sodic soil (under study). Probably the positive implications of cyanobacteria imposed upon their integration with the other applied amendments. On the other hand, significant increases in P and K uptake occurred in plants inoculated with *Arthrospira platensis*. This might take place because cyanobacteria synthesized chelator(s) (Du et al., 2019) and/or organic acids that mobilize the different insoluble forms of inorganic phosphate (Singh et al., 2016a). The synthesized chelators for Ca^{2+} shift the equation shown hereafter towards further increases in the solubility of P in soil as mentioned by Cameron and Julian (1988) and Singh et al. (2016b).

$$Ca_{10}(OH)_2(PO_4)_6 \rightarrow 10Ca^{2+} + 2OH^- + 6PO_4^{3-}$$

Thus, cyanobacteria recycle and enrich soils with soluble-P (Nõges et al., 2008). Moreover, these bacteria are characterized by the cell-specific P-uptake (Fu et al., 2005; Aubriot and Bonilla, 2012); hence, improved significantly the availability and uptake of P by the grown barley plants. In case of K, cyanobacteria have a relatively efficient K^+ uptake system under the saline - sodic conditions depending on both proton gradient and ATP (Berry et al., 2003) or through potassium selective channels (Checchetto et al., 2012). These cyanobacteria increased K availability and its uptake by the grown plants; hence, increased plant tolerance to this abiotic stress (Munns and Tester, 2008; Rady et al., 2018). It also uses this nutrient for the photosynthesis recovery of this bacterium (Qiu et al., 2004). It is worthy to mention that cyanobacteria could absorb Na^+ as an essential nutrient and cannot be replaced by other nutrients (Thomas et al., 1984). This might, in turn, improve the membrane permeability of the symbiont grown plants e.g. barley (Larbi et al., 2020).

Compost as a potential amendment for reclamation of saline-sodic soil

The application of compost at its highest rate (15 g kg^{-1}) decreased significantly soil EC and this is probably because: (1) this amendment minimized the activity of some soluble salts (Abdelhafez et al., 2018), besides, it improved soil aggregation (Elcossy et al., 2020) which consequently increased the removing of salts away from the top soil (Abdel-Ati and Eisa, 2015; Kamel et al., 2016; Pavani et al., 2019; Wang et al., 2019). (2) This amendment acts as barriers against capillary rise of water and salts (Chávez-García and Siebe, 2019), besides, it may retain soil moisture within the rhizosphere (Bassouny and Abbas, 2019; Menzies Pluer et al., 2020) which may dilute the salinity stresses. (3) This organic amendment also increased the solubility of Ca salts in soil and this might increase its capability to substitute adsorbed Na^+ on the clay minerals (Chaganti et al., 2015). Moreover, compost increased the solubility of $CaCO_3$ which dissolved and liberated more Ca ions to substitute adsorbed Na on clay minerals (Abdel-Ati and Eisa, 2015). These mechanisms played together in decreasing soil ESP (as presented in Fig 2); thus, reduced the sodic hazards in soil.

It seems that the application of 7.5 g compost kg^{-1} soil did not affect the dry weight of barley dry weight);however, its application at a rate of 15 g kg^{-1} improved significantly plant dry weight. This positive effect of such applied organic amendment was also detected by Abdel-Ati and Eisa (2015) and may be attributed to the significant increases that took place in NPK released to soil upon its decomposition; consequently uptake of these nutritive elements increased by the grown plants. Similar results indicated that N (Abdelhafez et al., 2017 & 2018 and El-Akhdar et al., 2018), P and K availability increased by the grown plants and therefore, their uptake increased in soil amended with compost (Abbas et al., 2011; Farid et al., 2018). Moreover, organic matter probably postponed the crystallization of amorphous calcium phosphate (Lei et al., 2018).

Phosphogypsum as a potential amendment for reclamation of saline-sodic soils

Application of phosphogypsum at a rate of 4.5 g kg^{-1} recorded no significant effect on soil EC; however, its application at a rate of 9 g kg^{-1} decreased significantly soil salinity. Also, this amendment decreased significantly soil ESP, especially with increasing its rate of application. This is because Ca ions (presented as a component of this amendment) replaced adsorbed Na on the exchange sites of soil minerals (Guo et al., 2006, Farid et al., 2014 and Helmi et al., 2018). Also the calcium ions increased soil aggregation through the cationic bridging (Wuddivira and Camps-Roac, 2007 and Amer & Hashim, 2018) and this might, in turn, increase the downward movement of salts away from the rhizosphere (Syed-Omar and Sumner, 1991), especially Na ions (Chaganti et al., 2015).

Phosphogypsum effect was also noticeable on dry weights of barley plants grown on the studied saline sodic soil; especially with increasing the rate of its application. This is because the phosphogypsum amendment raised considerably the concentrations of Ca^{2+} in soil (Amer and Hashim, 2018) which protect plant cell membrane from the hazards of salinity (Misra et al., 2001); beside of the ameliorating effects of this amendment on soil. This considerably increased the total yield of barley grown on such adverse conditions (Amer and Hashim, 2018). Moreover, significant increases in NPK availability occurred in phosphogypsum amended soils Probably, phosphogypsum increased soil hydraulic conductivity (Rasouli et al., 2013) besides, it increased significantly organic N mineralization (Bailey, 1995); hence, improved NH_4^+ mobility in soil (Favaretto et al., 2012). Accordingly, application of phosphogypsum significantly enhanced the nitrogen use efficiency by crops grown on salt affected soils (Murtaza et al., 2017). It also slows down P loss from soils (Uusitalo et al., 2012); besides, it decreased soil pH (Murtaza et al., 2017) and this consequently increases P- solubility in soil. The positive effect of phosphogypsum on K uptake can take place through minimizing the Na/K ratio within plants (Khan et al., 1996) while decrease the leakage of K^+ in parent cells (Swapnil and Rai, 2018). Generally, phosphogypsum application seemed to be more efficient on minimizing the implications of soil salinity and sodicity than the organic compost did.

Integrated amendments as potential tools for reclamation of saline-sodic soils

Four integrated amelioration techniques were highlighted in this study to investigate their positive consequences on improving soil characteristics and plants grown thereon. Generally, the outcomes of dual amendments seemed to be more promising on both soils and plants than the single ones did. (1) The dual application of compost and phosphogypsum recorded further significant reductions in both soil EC and ESP. This combination also improved NPK availability; hence improved their uptake and growth of barley plants beyond those attained for the single treatments. Accordingly, the authors support the first integrated approach. (2) Soaking seeds in *Arthrospira platensis* together with application of phosphogypsum as a soil amendment also decreased soil EC and ESP, especially upon application of the highest rate of phosphogypsum. Such a technique raised; on the other hand, the available contents of NPK in soil, and improved their uptake by plants. This optimistically resulted in significant increases in the growth of barley plants grown under the saline-sodic conditions. Thus, the authors also encourage using the second integrated approach for ameliorating saline-sodic soils. (3) Inoculating seeds with *Arthrospira platensis* in presence of compost also recorded positive effects on soil chemical characteristics and plants grown thereon similar to those attained due to the dual application of *Arthrospira platensis* + phosphogypsum and; therefore, the authors promote the third integrated approach. It is worthy to mention that the combination among the three investigated ameliorating treatments i.e. bio-, organo- and chemical treatments recorded further positive significant effects on soil chemical characteristics and plants grown thereon beyond those attained for the effects of the dual amendments. In this concern, triple combination reduced soil ESP, when applied at their highest rates, by more than 50%, while increased barley dry-weight by approximately 40%. Thus, authors recommend the fourth integrated approach.

In conclusion, the above-mentioned results highlighted the positive effects of integrated treatments i.e. *Arthrospira platensis*, compost and phosphogypsum in dual and triple combinations to raise the productivity of barley plants grown on salt affected soils under no leaching conditions on one hand; while lessening soil degradation in terms of soil EC and ESP on the other hand. However, more investigations are required under field conditions for long time periods to acquire more reliable results.

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