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Influence of environmental-friendly bio-organic ameliorants on abiotic stress to sustainable agriculture in arid regions: A long term greenhouse study in northwestern Egypt

Abstract

The problem of soil salinity is rapidly increasing, with more than 950 million hectares affected by salinity stress (Arora et al., 2017). The amelioration of saline-sodic soils using chemical ameliorates could increase CO_2 emissions and soil degradation. Therefore, amending saline-sodic soil with environmentally friendly bio-organic ameliorants such as brewer's spent grain (SG) and *Azospirillum* (*A. brasilense*) bacteria could represent *a* safe and cheaper approach compared to other organic (compost; CT) and mineral fertilizers. Under greenhouse conditions, maize was grown in saline-sodic soil amended with bio-organic ameliorants. Nine treatments were included; (i) SG1 (23.8 t ha^{-1}); (ii) SG2 (47.6 t ha^{-1}); (iii) TC1 (23.8 t ha^{-1}) ; (iv) TC2 (47.6 t ha^{-1}); (v) injection of *A. brasilense* with corn seeds (Az); (vi) combination of *A. brasilense* and SG (Az+SG1); (vii) combination of *A. brasilense* and compost (Az+TC1); (viii) mineral fertilizers (NPK) and (ix) the control (CK). The results revealed that soil amended with Az and SG2 significantly decreased the exchangeable sodium percentage (ESP) and higher cation exchange capacity (CEC). Compared with the control, the exchangeable sodium (Ex-Na^+) concentration was decreased by 53.2 and 49.27%, for Az and Az+SG1 treatments, respectively. The fresh- and dry weight observed for Az+SG1, SG2, and Az treatments were increased compared to TC1, TC2, NPK, and CK treatments. The grain and biological yields were higher in Az+SG1 and SG2 than in TC2, NPK ameliorants, and CK. The bio-organic ameliorants alleviated the abiotic stress, enhance the growth and productivity of corn plants, decrease soil ESP and Na^+ content, and enhance soil fertility. In conclusion, the application of SG2 can enhance the growth, and productivity of maize grown under salinity-sodicity stress. Therefore, SG2 and Az+SG1 are recommended for direct application in saline-sodic soil.

Keywords: Land degradation, greenhouse, environmental-friendly amendments, arid regions, bio-organic ameliorants.

1. Introduction

Salinity-sodicity stress is a major problem that spreads in more than 100 countries, threatening environmental health, agricultural production, and food security. The problem is aggravated by the rapid increase in food production (Arora et al., 2017). Soil salinity results due to the buildup of soil soluble salts in the rhizosphere (Diacono and Montemurro, 2015). Water loss through evapotranspiration in water-demanding agri-food systems in particular under hot- and hot-dry environments increases the severity of soil salinity (Diacono and Montemurro, 2015). Secondary, salinization may be caused by irrigation practices, in particular when saline water is used for irrigation (Morsy et al., 2022). Salinity stress negatively affects soil physico-biochemical properties, thus crop growth and development. In salt-affected soils, the increase of Na^{+} leads to the de-flocculation of clay particles (Mahmoodabadi et al. 2013; Zhao et al. 2018; Erel et al. 2019), thus, decreasing the hydraulic conductivity and water infiltration capacity of the soil, therefore the water-holding capacity could be reduced (Abdallah et al., 2019). Plants grown in salt-affected soils suffer nutrients deficiency, therefore farmers add more fertilizer, increasing environmental pollution, and the production cost. The deficiency of nutrients is a side effect of soil salinity and may result from soil alkalinization and ion competition (Morsy et al., 2022). Consequently, soil salinity affected soil biological activities and crop yield production (Rath and Rousk, 2015; Rojas-Tapias et al. 2012; Hafez et al. 2021).

Brewer's spent grain (SG) was used as a soil amendment as a win-win solution; recycling industry organic wastes and enhancing soil fertility (Hafez et al., 2019, 2020, 2021). Brewer's SG constitutes approximately 25.4, 21.8, 11.9, 24.0, 10.6, and 2.4% cellulose, arabinoxylan, lignin, protein, lipid, and ash, respectively (Mussatto and Roberto, 2006). Besties minerals, vitamins, and amino acids, the presence of protein (21%), indicates high N content in the SG, encouraging its reuse in the compost industry for agricultural use. The mineral composition of SG includes Ca^{2+}, Co^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, Mg^{2+}, k^{+}, Na^{+}, Se, P, and S, each with a concentration of lower than 0.5% (Mussatto and Roberto, 2006; Rashad et al., 2016). Due to its chemical composition, the SG has been reused for several applications, in particular as a soil amendment for enhancing the soil's physico-biochemical properties (Hafez et al., 2019, 2020, 2021).

Plant growth-promoting rhizobacteria (PGPR) positively affect plant growth through N-fixation, increasing P availability. The PGPR delivers several means of substituting mineral fertilizers, thus decreasing environmental pollution and increasing food safety (Sandeep et al., 2021). Therefore, representing possible instruments for sustainable agriculture and future developments. Nearly, 2 to 5% of the rhizosphere bacteria are PGPR (Negm and Abu-hashim, 2019). The soil is naturally fertile when the soil organisms release inorganic nutrients at a sufficient rate to sustain rapid growth. PGPB tolerates a broad range of salt stress and encourages plants to withstand salinity through hydraulic conduct, osmotic accumulation, toxic sodium removal, higher osmotic activity, and photosynthesis (Yu et al., 2019). In this way, PGPR represents a promising approach to that alleviating salt stress and increasing the productivity of salt-affected soils (Arora et al. 2017).

Organic amendments enhance the utilization of nutrients by plants and reduced nutrient losses by improving soil water retention (Abdallah et al., 2019; Shehzadi et al., 2014; Zaghloul, 2020). Therefore, compost ameliorants positively increased crop yield (Liu et al. 2019). A field experiment proved that farm yard manure, humic acid, or *Azotobacter* inoculum alone and combinations were rich N, P, and K sources for maize plants' requirements. The objective of the present study was to evaluate the effects of organic and biological ameliorants on alleviating the harmful effects caused by abiotic stresses (salinity and sodicity stress). We evaluated the influence of organic and biological ameliorants on soil chemical properties, soil fertility, and the growth and productivity of maize plants grown in saline-sodic soil under greenhouse conditions.

2. Materials and methods

2.1. Soil characteristics

A two-season experiment (2017-2018) has been conducted under greenhouse conditions in the New Borg Arab City (30˚ 53ˈ 33.17" N 29˚ 22ˈ 46.43" E of altitude), Alexandria, Egypt. The climate of the region is typically Mediterranean, with hot and dry summer and cool-wet winter (FAO, 2016). The average annual temperature is 25.6℃, while the annual precipitations are amounts to 130 mm. The soil of the study site is a saline-sodic (EC of 5.43, pH of 8.84, and ESP of 53.1%0). The chemical properties of the soil are given in Supplementary Table S1. The soil is clay loam in texture, with soil fractions of 45.3, 23.5, and 31.2% for clay, silt, and sand, respectively. Soil texture was measured using the hydrometer method (Anderson et al., 1982).

2.2. Soil organic and biological ameliorant's description

Four soil bio-organic ameliorants' have been used, i.e., *Azospirillum brasilense (A. brasilense)*, SG, compost, and mineral fertilizers, which have been applied individually and in combination). Before sowing, a cultivated suspension of *A. brasilense* (Az), was soaked with the seeds for four hours. Moreover, Az was injecting three times into the soil and in irrigation water. The SG is a by-product of organic waste in the beer industry, and compost was from agricultural organic waste. The soil amendments applications methods are shown in Fig. 1. Our previous work calculates the basic properties and describes the basic properties (Hafez et al., 2020b).

Fig. 1. Greenhouse experiment preparation from experiment design to bacteria inoculants with seeds-soil under saline-sodic soil.

Where: (1)- is seed inculcation with *Azospirillum* bacteria; (2)- random distribution pots.

2.3. The experimental details and preparation

In the current study, nine treatments/ameliorants were studied comprising; (i) SG1 (23.8 ton ha^{-1}) and (ii) SG2 (47.6 t ha^{-1}); (iii) TC1 (23.8 ton ha^{-1}) ; (iv) TC2 (47.6 ton ha^{-1}); (v) injection of *A. brasilense* (Az) (with corn seeds); (vi) combination of *A. brasilense* and SG (Az+SG1); (vii) combination *A. brasilense* and compost (Az+TC1); (viii) mineral fertilizers (NPK) (178: 70: 100 units of N, P, and K, in the forms of urea, Ca $(PO_4)_2$, and $K_2(SO_4)$, respectively) and (ix) the control (CK). The details of the experimental treatments were summarized in Table S2. Ameliorants were mixed with the soil (30 kg) and moved to pots using three replicates. The pots were placed in a greenhouse.

The experiment consisted of 27 pots (nine treatments x three replicates), each containing 25 seeds of maize. After successful germination, three plants were left for each plot. The experimental units (pots) were arranged in a split-plots in a randomized complete block design. To avoid interference between the pots, they were placed 30 cm apart. The depth of applied water was estimated according to the potential crop evapotranspiration (mm d^{-1}) and crop coefficient (Kc) of corn (Allen et al. (1998). The ETc was calculated using the following equation:

$$ETc = Ev \times Kp \times Kc$$

Where Ev, Kp, and Kc are the evaporation from a class A pan (mm), pan coefficient, and crop coefficient, respectively.

2.4. Soil chemical analysis

The pH was determined in a 1:2.5 w/v soil: water suspension (Anderson et al., 1982). The EC was measured using an EC meter in saturated paste extracts (Corwin and Yemoto, 2017). Total N was measured by the Kjeldahl digestion method. Available P.was extracted with $NaHCO_3$ and measured using a spectrophotometer .at a wavelength of 880 nm. Available K was extracted by ammonium acetate solution (1 N) and measured by the flame. photometer. The N, P, and K were measured according to Anderson et al., (1982). DTPA solution was used for the extraction of available Fe^{2+}, Zn^{2+}, Mn^{2+}, Cu^{2+}, and B^{+} and was measured using atomic emission spectroscopy (Soltanpour and Schwab, 1977). Soil organic carbon was measured by the oxidization method using $K_2Cr_2O_7$ (Ouyang et al., 2013). The Exh-Na^{+} was extracted with ammonium acetate solution (1 M) (Normandin and Miller, 1998). Soil CEC was estimated following the

Bower saturation method as outlined by (Richards 1954). The soil ESP was calculated using the following equation;

$$ESP\ (\%) = \frac{\text{Exchangeable} - \text{Na}}{\text{CEC}}\, x\ 100$$

2.5. Plant and yield measurements

The leaves of three plants were selected for each treatment. The leaf and ear corn samples were collected at plant harvest. The plant leaf was collected when 70% of the pots' plants emitted the tassel to determine the leaf N, P, and K concentrations following the methodology (AOAC, 2006). Maize productivity components, i.e., fresh and dry weight (g), biological yield (kg), the mass of 100 grains (g), and grain yield (GY; g $plant^{-1}$) were determined (AOAC, 2006).

2.6. Statistical analyses

Analysis of variance ANOVA was conducted using the SPSS program. Treatments' means were separated using the LSD test at $P < 0.05$.

3. Results and discussion

3.1. Effect of bio-organic ameliorants on abiotic stress indicators.

3.1.1. Exchangeable sodium percentage (ESP)

Increasing sodium concentration comparable to the other exchangeable cations (Ca, Mg, and K), increases soil ESP. The ESP was significantly decreased due to the application of organic and bio-organic ameliorants (Table 1). Additionally, ESP levels were reduced with *A. brasilense*, SG, and compost amendments (Fig. 2). After corn plant harvest, the ESP values were descending as follows: 51.74, 50.47, 27.42, 25.54, 18.74, 17.24, 17.06, 12.09, and 11.24 for the NPK > CK > SG1 > TC1 > TC2 > Az > Az+TC1 > SG2 > Az+SG1. Except for the control and NPK, all ameliorants reduced the soil ESP to less than 15%. Before soil amendments, the ESP was 53.1%, while after organic and biological soil amendments ranged from 27.42 to 11.24%. The applications of SG2 and the combination of *A. brasilense* with SG decreased the ESP by 77.74 and 78.83% for SG and Az+SG1 ameliorants. The SG and Az ameliorants decreased the Exc-Na^+ and soil sodicity than the TC1, TC2, NPK, and CK. This reduction in the ESP levels could be attributed to that Az with SG1 ameliorants enhanced soil microbial activity and organic matter decomposition rates. Our results support those of Hafez et al. (2020a) through laboratory incubation of saline-sodic soil for 60 and 160 days. A positive correlation has been observed between Exc-Na^+ and organic and biological amendments. The Az increased microbial biomass, which decreased the Exc-Na^+ in soil solution; this was positively correlated (r= 0.84) with SG2 and Az+SG1 ameliorants in soil. The addition of organic amendments to salt-affected soil can decrease soil salinity and enhance microbial biomass. Our results are in accordance with the results of Zhen et al., (2014) and Zhang et al., (2019). The decrease in ESP of saline-sodic soil due to organic amendments was also observed by Sastre-Conde et al., (2015) and Meena et al., (2019).

Table 1

Effect of bio-organic ameliorants on abiotic stress indicators and soil fertility parameters after 90 days after seed sowing in the amended soil.

Soil-ameliorants	excengable Na^+ percentage	excengable Na^+ concentration	**Cation exchange capacity**	**Total N**	**Available P**	**Available K^+**
	%	meq $100g^{-1}$	cmol+kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}
CK	50.47 a	2.767 b	5.51 f	0.03 f	2.022 d	55.25 e
NPK	51.74 a	2.676 b	5.17 ef	0.65 e	3.297 d	88.40 de
SG1	17.06 c	2.025 c	11.86 c	0.89 d	6.357 c	195.78 b
SG2	12.09 cd	1.699 d	14.04 a	1.37 b	15.464 a	255.84 a
TC1	27.42 b	3.118 a	11.38 c	0.63 e	3.078 d	112.71d
TC2	25.54 b	3.235 a	12.64 b	0.90 d	5.993 c	154.05 c
Az	18.74 c	1.292 e	6.90 e	1.98 a	16.831 a	176.67 bc
Az+SG1	11.24 d	1.414 e	12.57 b	1.24 c	9.727 b	271.44 a
Az+TC1	17.24 c	3.146 a	8.70 d	0.94 d	6.927 c	123.04 bc
$LSD_{0.05}$	5.00	0.327	0.662	0.139	1.900	41.30

Data corresponding to the means of three replicates followed by the same letter are non-significantly different using the least significant difference (LSD) test at $p \leq 0.05$. For a detailed description of treatments, see table S2.

Fig. 2. Effect of organic amendments on the exchangeable sodium percentage (ESP) after 90 days after seed sowing in saline-sodic soil. Values (mean ±SD; N=3) with similar letters are non-significantly different at $p \leq 0.05$. For a detailed description of treatments, see table 2.

3.1.2. Exchangeable sodium (Exch-Na^+)

The Exch-Na^+ concentrations followed this order: Az < Az+SG1 < SG2 < CK < NPK < TC1 < TC2 < Az+TC1, (Fig. 3). The soil amelioration applied varied in its impact on the Exch-Na^+ concentrations (Table 1). The Az and Az+SG1 ameliorants possessed the lowest Exch-Na^+, compared to the two levels of compost application rates. The trend amount of Exch-Na^+ concentrations is similar to soluble Na^+ expects TC1 and TC2 ameliorants.

The Az, Az+SG1, SG2, SG1, and NPK treatments decreased the Exch-Na^+ concentrations by 53.2, 49.27, 38.76, 26.8, and 3.2%, respectively. On the other hand, the two compost level applications increased the Exch-Na^+ concentration by 12 and 38% for TC1 and TC2, compared to control. This result could be explained by the high salinity of compost ameliorants before the addition to the soil. The *A. brasilense* and SG as a soil amelioration ($P < 0.05$) decreased the soil Exch-Na^+ contents by increasing the CEC and exchangeable Ca^+ and K^+ contents on the soil surface. Thus, the combination of SG-limited Exch-Na^+ concentrations may absorb Exch-Na^+ as sodium humate forms or expulsion from the root zone to the soil profile. Obtained results are in accordance with those of Zhang et al. (2008), who revealed that the inoculation with bacteria could limit the influx of Na^+ into roots. Further, it reported that *Bacillus* bacteria inoculation to soil could mediate salt tolerance. Other researchers also observed the applications of organic matter to the chemical properties of saline soils positively impacted soil sodium concentration (Ashraf and Foolad, 2007; Bano and Fatima, 2009; Rojas-Tapias et al., 2012; Zhang et al., 2008; Galindo et al., 2020). Our results revealed the beneficial effect of SG, Az, and their combinations as soil amendments for the saline-sodic soils (Yu et al., 2019, 2015).

Fig. 3. Effect of soil-ameliorants on soil exchangeable Na^+ ($meq100g^{-1}$). Values (mean ±SD; N=3) with similar letters are non-significantly different at $p \leq 0.05$. For a detailed description of treatments, see table S2.

3.1.3. Cation Exchange Capacity (CEC)

The CEC was increased with the addition of all ameliorants compared to CK and NPK treatments which recorded the lowest CEC (Table 1). This significant increase in the CEC could be attributed to the accumulated and released Ca^{2+} Mg^{2+} and K^+ soluble micronutrients from organic and biological amendments and adsorbed on the soil particle. Relative to the control, the CEC increased by 154.8, 129.4, and 128.1%, respectively, for SG2, TC2, and Az+SG1 treatments. No differences were observed between (CK and NPK) and (TC2 and Az+SG1) ameliorants. Organic amendments reduced the ECe, ESP, and SAR more than that of the control treatment and saturated the exchange complex with Ca^{2+}. Hafez et al. (2020a) reported the application rate of *A. brasilense,* SG, and compost is safe and sufficient for macronutrient consumption and increased the soil Ca^{2+}, Mg^{2+}, and K^+ concentrations.

3.2. Effects of bio-organic ameliorants on soil fertility

3.2.1. The essential soil macro-nutrients (N, P, and K)

All organic and biological soil ameliorants increased total N (TN), available P (Av-P), and available potassium (Av-K) compared to the control (Table 1). The percentage increases varied from 2166 to 6600% for TN, 162 to 833% for Av-P, and 160 to 491% for Av-K. Therefore, all organic and biological amendments efficiently contributed soil TN, Av-P, and Av-K . The soil amendments increasing TN and Av-P followed the order: Az > SG2 > Az+SG1 > Az+TC1 > TC2 > SG1 > NPK > TC1 > CK. While for Av-K followed the order: Az+SG1 > SG2 > SG1 > Az > TC2 > Az+TC1 > TC1 > NPK > CK. The Az and SG2 ameliorants possessed the highest level of TN and Av-P compared to the CK, NPK, TC1, and TC2 ameliorants. The trend of Av-K concentrations increased with the combination of Az and SG1 ameliorants. The Az+SG1 treatment increased the Av-K concentrations by 491% compared to the control (Table 1).

SG and Az ameliorants' application rates were superior in TN, Av-P, and Av-K on TC1 and TC2 organic ameliorants. The mineralization of organic amendments leads to increases in the soil total N, available P, and available K. Organic ameliorants used in the present study have considerable rates of readily decomposable soil organic matter, which are mineralized and increased SOC and nutrients concentrations. Furthermore, the organic amendments must be added before seed sowing to have enough time to mineralize organic compounds, thus increasing soil-plant macro-nutrient availability (Galindo et al., 2020). The effect of *A. brasilense* and SG on the soil reclamation enhanced total N, available P, available K, maize seed germination, plant growth, and soil fertility (Rashad et al., 2016; Hafez et al., 2021)**.** Abdelraouf et al. (2020) found the applications of organic biochar amendments enhanced the total N and available K under the sweet pepper plants.

3.3. Effect of bio-organic ameliorants on corn parameters after three weeks and three months

3.3.1. Macronutrient's concentrations

Fig. 4 and 5 showed the N and P concentrations in plants after three weeks and three months of seed sown for using organic and biological ameliorants. N and P contents in plants increased in this order: Az ≥ Az+SG1 > SG2 > TC2 > SG1 > TC1 > Az+TC1 > NPK > CK. The *A. brasilense* treatment and SG with *A. brasilense* enhanced the total N and available K compared to the control and NPK ameliorants during the growth period. Still, it did not affect the Az+TC1 and TC1 ameliorants. P concentration was similar to concentration N in all ameliorants except SG2 possessed a higher P concentration than all ameliorants in the same levels.

On the other hand, after three months of seed sowing, N and P trends were similar to the trend N and P concentrations after three weeks. These results were compatible with Hafez et al., (2019), where these authors reported that Az use on corn increased N, P, and K concentrations. When studying the effect of different organic ameliorants on the highest macronutrient concentrations, corn was achieved when treated with Az and SG2 fertilization, increasing N and P compared to control treatment, due to N fixation by *Azospiillum* as a plant growth-N fixation bacterium. These results agree with Soumare et al. (2020)

The positive effect of SG2 and Az ameliorants on macronutrient contents of maize crop confirms the observed increase in N, K, and P in the wheat crop due to the use of SG and *A. brasilense* as soil amendments (Hafez et al., 2021). The foliar spray with humic substance, i.e., ALCRI-Help and ALCRI-Help-M enhanced NPK concentration in wheat (Hafez et al., 2021).

Fig. 4. Effect of soil-ameliorants on total nitrogen (TN, %) concentrations in corn plant after three weeks and 90 days after seed sowing in saline-sodic soil. Values (mean ±SD; N=3) with similar letters are non-significantly different at $p \leq 0.05$. For a detailed description of treatments, see table S2.

Fig. 5. Effect of soil-ameliorants on total phosphorus (TP, %) concentrations in corn plant after three weeks and 90 days after seed sowing in saline-sodic soil. Values are the mean ±SD (N=3). Values with similar letters are non-significantly different using the LSD test at $p \leq 0.05$. For a detailed description of treatments, see table S2.

3.3.2 Fresh and dry weight (g)

Organic additives amended with *A. brasilense* inoculation significantly increased fresh- and dry weights (Fig. 6 and 7). However, Az+SG1 and Az ameliorants increased fresh and dry weight more than the CK and NPK ameliorants. The fresh weight amended Az+SG1 and Az was 403.16 and 370.73 g compared to 100.2 and 117.5 g for CK and NPK, respectively. *A. brasilense* ameliorants and SG increased fresh weight more than compost ameliorants, which gave a lower fresh weight. This result is consistent with the findings of Hafez et al., (2019) who revealed that organic amendments with *A. brasilense* had higher fresh and dry weight for corn plants than mineral fertilizer. On the other hand, the dry weight of the organic and biological ameliorants followed the order: Az+SG1 > Az > SG2 > TC2 > SG1 > Az+TC1 > TC1 > NPK > CK. The Az and Az+SG1 amendments possessed the highest values of dry weight after 90 days after seed sowing. The Az+SG1 treatment was found to have greater fresh- and dry weights due to N fixation by *A. brasilense* bacteria as biological N fixation and macronutrient mineralization by organic additives. These results agree with Sahoo et al., (2011) and Zaeim et al., (2017). The fertilization with NPK had non-differences compared with organic and biological ameliorants. These were increased in fresh and dry weight by organic and biological additives in saline-sodic soil after 90 days after seed sowing and were compatible with increasing macronutrients in soil and plant at the same time of the experiment (Neweigy et al., 1997; Zahra et al., 2019; El-Yazal et al., 2020).

Fig. 6. Effect of soil-ameliorants on corn fresh and dry weights (g plant^{-1}) after 90 days of sowing in saline-sodic soil. Values (mean ±SD; N=3) with similar letters are non-significantly different at $p \leq 0.05$. For a detailed description of treatments, see table S2.

I 1 ffect of soil-ameliorants on the growth of the 2 ants after a month of sowing in saline-sodic soil.

Where: (1)- corn plants seed germination after 21 days of seed sown and (2)- corn plant growth after 30 days of *Azospirillum* seed inculcation and soil amendments.

3.3.3. Grain yield (GY)

Organic and biological amendments ($P < 0.05$) increased the GY (g plant^{-1}) of corn plants grown in saline-sodic soil (Fig. 8). The GY per plant increased by 916, 903, 562.36, 555.31, 529.6, 250.87, 238.62, and 37.19%, respectively, for Az+SG1, SG2, TC2, SG1, Az, TC1, Az+TC1, NPK compared with the CK. Among all treatments, the combination of Az with SG1and SG2 amendments gave the highest GY. These observations highlighted the importance of N, P, and K availability for corn plants to enhance the GY because the SG1 with Az and SG2 was the source of NPK. Therefore, SG2 and Az+SG1 are recommended for direct application in saline-sodic soil to increase GY. Oliveira et al. (2018) also reported a positive role for *A. brasilense* in the growth and yield improvement of corn plants. The agro-industrial with *A. brasilense* ameliorants to soil produced growth regulators, such as auxins and gibberellin and cytokinins and polyamines, and amino acids (Hafez et al., 2019). The *A. brasilense* as plant growth-promoting bacteria enhanced the plant growth, GY of many crops, water adsorption, and organic minerals that eventually increased seed yield and corn plants (Sinha, 2009; Swarnalakshmi et al., 2013).

Fig. 8. Effect of soil-ameliorants on corn grain yield (g plant^{-1}) in saline-sodic soil. Values (mean ±SD; N=3) with similar letters are non-significantly different at $p \leq 0.05$. For a detailed description of treatments, see table S2.

3.3.4. Biological yield

The ratio of GY to shoot and root yield is a key indicator for the photosynthetic activity of crops. The effect of different ameliorants on the biological yield of maize grown in the saline-sodic soil is illustrated in Figure 9. The biological yield of corn plant was the following order: Az+SG1> SG2 > Az > TC2 > SG1 > Az+TC1 > NPK > CK. Az+SG1 and SG2 ameliorants affected biological yield (Fig. 9). The Az+SG1 and SG2 ameliorants possessed the highest biological yield was 646.83 and 580.80 g plant^{-1}; this increase was 326.86% and 283.29% compared to the control. Since grains are a component of the biological yield, a significant increase in GY could lead to an increase in the biological yield. Similar results were observed by Ahmad et al. (2013) where a significant increase in the biological yield of maize was recorded due to organic and biological ameliorants. Similarly, Oliveira et al. (2018) reported a positive role for *A. brasilense* on plant growth and yield improvement of maize. The application of Az and organic matter enhanced wheat plants' grain and biological yields by 256 and 370%, respectively (Hafez et al., 2021). As expected, the effect of chemical fertilizers (NPK variant) on the biological yield of maize was the weakest. In this regard, the introduction of mineral fertilizers in saline-sodic soils, in our opinion, is not recommended.

Fig. 9. Effect of soil ameliorants on biological yield (g plant^{-1}) of corn plants in saline-sodic soil under greenhouse. Values (mean ±SD; N=3) with similar letters are non-significantly different at $p \leq 0.05$. For a detailed description of treatments, see table S2.

Conclusion

The combination of *A. brasilense* with organic sources as bio-organic ameliorants alleviated the negative impacts of abiotic stress induced by soil salinity. The reclamation of the saline-sodic soil indicated that SOC, N, P, and K were increased with SG2 and Az+SG1 ameliorants. At the same time, EC and ESP, Exch-Na$^+$ concentrations were higher with two compost rates. Moreover, the injection enhanced phosphorous availability; decreased the negative effect for EC and Exch-Na$^+$ after 90 days of ameliorants applications in the greenhouse. Applying *A. brasilense* with the SG decreased soil salinity. The first amendment rate of SG and compost (SG1, TC1) was not different than the second rate (SG2, TC2). However, the compost ameliorants are not recommended for saline-sodic soil reclamation. On the other hand, the Az with SG ameliorants enhanced GY, fresh and dry weight, and biological yield compared with other mineral ameliorants. Therefore, SG2 and Az could be ideal amendments for saline-sodic soil that effectively increase nutrient availability and corn growth and productivity. The bio-organic ameliorants positively affected abiotic stresses to enhance corn plants' growth rate and productivity, decrease soil ESP and sodium contents, and enhance soil fertility properties under greenhouse conditions. Therefore, SG and Az applications could be used for the amelioration of the saline-sodic soil. Finally, individual or combinations of SG and *Az. brasilense* ameliorants are recommended for enhancing the fertility of the saline-sodic soils as well as the GY of corn plants.

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