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TAYMAA IBRAHEEM*, MOHAMMAD-ALI HAJABBASI*, HOSSEIN SHARIATMADARI*, BANAFSHEH KHALILI*, MOHAMMAD FEIZI**

EFFECTS OF APPLIED BIOCHAR AND MUNICIPAL SOLID WASTE COMPOST ON SALINE SOIL PROPERTIES AND SORGHUM PLANT ATTRIBUTES

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Abstract. The hypothesis is that incorporating saline soil with biochar or compost reduces the deteriorating effects of salinity. The pot experiment was irrigated with waters with different salinities (4.5 and 9 dS m^{-1}) and a silty clay soil in pots was thoroughly mixed with 1.5% w/w of biochar, 1.5% w/w of municipal solid waste compost and the mixtures of 0.5 × 0.5% w/w of the two mentioned substances. Irrigation was provided to realize 0.15 leaching fractions for equilibrating the soil salinity. Soil and plants were analysed after two months (T1) and three months (T2) after sowing. Saline irrigation water decreased SAR (~45%) and SOC (~5.5%), respectively for T2 compared with T1. The biochar treatment reduced the amount of ECe in T1 and T2. Both irrigating with saline water and amendments greatly changed the amount of leaf water potential (LWP), chlorophyll and proline leaf. LWP and proline were increased by 17 and 76%, respectively, with increasing irrigation water salinity, while the leaf chlorophyll content was significantly decreased (~52%). The overall finding was that incorporating the saline soil of the region with biochar showed more potential to enhance soil properties and sorghum production.

Keywords: saline soil, amendment, saline water, proline, sorghum

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* Department of Soil Science, College of Agriculture, Isfahan University of Technology, Isfahan 84156-83111, Iran. Corresponding author: t.ibraheem@ag.iut.ac.ir

** Isfahan Agricultural and Natural Resources Research and Education Centre, Iran.

LIST OF ABBREVIATIONS

ECw – electrical conductivity of irrigation water (dS m^{-1})
ECe – electrical conductivity of the saturated paste extract (dS m^{-1})
B – biochar
C – municipal solid waste compost
BC – combination of biochar and municipal solid waste compost
BT – biochar treatment at a rate of 1.5% w/w
CT – municipal solid waste compost treatment at a rate of 1.5% w/w
BCT – combination of B and C treatment at a rate of 0.5 × 0.5% w/w
LF – leaching fractions (%)
LWP – leaf water potential (bar)
SAR – sodium adsorption ratio (mmol $l^{-1})^{-1/2}$
OC – organic carbon (%)
T1 – two months after sowing
T2 – three months after sowing

INTRODUCTION

Soil salinity is a globally increasing problem and one of the main obstacles to agricultural productivity, especially in the dry regions where irrigation is vital. Salinity is a major environmental factor limiting the productivity of more than 800 million hectares of the agricultural land (Goyal *et al.* 2016). This accounts for more than 6% of the world's total land area (Munns and Tester 2008). The Food and Agriculture Organization of the United Nations (FAO) estimates that globally, out of 1,500 million hectares of the dry land agriculture, 32 million hectares (2%) are affected by secondary salinity to varying degrees (FAO 2000). Of the current 230 million hectares of the irrigated land, 45 million hectares (20%) are salt-affected soils (Munns and Tester 2008). Soil salinity becomes a problem when the total amount of salts accumulated in the root zone is high enough to negatively affect plant growth (Warrence *et al.* 2002). Excessive amounts of salts have adverse effects on the physical and chemical properties and soil microbiological processes and, thus, on plant growth (Tejada *et al.* 2006).

Reclaiming of these saline soils generally involves two processes: leaching of soluble salts (saline soils) and replacing exchangeable Na^+ for the sodic soils by Ca^{+2} (Fernandes *et al.* 2019). Applying soil amendments is another way of easing the reclamation. Addition of organic amendments under saline conditions has already been shown to have positive impact on soil properties (Grattan and Oster 2003, Mavi and Marschner 2013, Zhang *et al.* 2015).

Pyrolysis of biomass residues under limited oxygen supply results in the production of carbon-rich materials, known as "biochar". Different organic materials such as green residues, animal manures, and agricultural leftovers can be used for producing biochar (Abrishamkesh *et al.* 2015). Biochars are characterized based on their feedstock properties from which they are made and the pyrolysis conditions such as temperature and duration (Demirbas 2004, Chan and Xu 2009, Laghari *et al*. 2016). Some controversial reports are devoted to the effects of biochar on soil characteristics (Lehmann *et al*. 2006, Abel *et al*. 2013, El Hiyar *et al*. 2017, Eissa 2019). Recently, several studies reported on the results of biochar application as a conditioner in saline soils (Wu *et al*. 2014, Sappor *et al*. 2017, Rekaby *et al*. 2021). According to Wu *et al*. (2014) and Usman *et al*. (2016), biochar application reduced sodium ion (Na^+) uptake, increased potassium (K^+) uptake, and increased soil organic carbon (SOC) content in saline soils. Reports also show that biochar application can improve water holding capacity, water availability and reduce ionic risk (Kammann *et al*. 2011, Novak *et al*. 2012), decrease salt accumulation in solution and dispersion of surface soil particles (Thomas *et al.* 2013) and improve leaf chlorophyll contents (Akhtar *et al*. 2015a).

Nowadays a rapid increase in the amount of municipal solid waste is obvious, basically due to the rise in population and economic development. The term "municipal solid waste" (C) means waste from households and related materials such as plastics, metals and organic residues (Meena *et al*. 2019). Utilizing the municipal solid waste compost could be a promising alternative to alleviate the adverse effects caused by soil salinization (Lakhdar *et al*. 2008, Wu *et al*. 2014). Municipal solid waste compost represents a source of slow-release N and P, and other nutrients improving soil fertility and also contribute to an increase in the productivity of the salt-affected soils (Lakhdar *et al*. 2008, Oueriemmi *et al*. 2021). On the other hand, by applying municipal solid waste compost it is possible to increase organic matter content, improve soil aggregate stability, hydraulic conductivity and porosity (Meena *et al*. 2019, Yüksel and Kavdır 2020).

Leogrande *et al*. (2016) also showed that applied compost (C) may directly increase the concentration of Ca^{+2} and K^+ in soil and improve soil fertility. Walker and Bernal (2008) suggested that the application of compost (produced from the olive oil industry) led to an enrichment of the exchange complex in Ca^{+2} and Mg^{+2}, decreasing Na^+ in the exchange complex and was particularly relevant in the reclamation of saline-sodic soils. Organic amendments such as biochar (B) derived from rice husk, solid waste compost (C), and a mixture of biochar and municipal solid waste compost (BC) were used to investigate their effects on remediation of a saline-sodic soil of central Iran. The study was also undertaken to determine the effects of irrigation water salinity and different rates of biochar and municipal solid waste compost on some soil and plant properties.

MATERIALS AND METHODS

Experimental soil characteristics

Surface soil (0–30 cm) samples collected from Rudasht Research Experiment Station of Isfahan province (E52°53', N32°34') were Typic Haplosalids, Fine Mixed (Soil Survey Staff 2003). The electrical conductivity (ECe) and sodium adsorption ratio (SAR) of the soil samples in saturated paste extracts were 14 dS m^{-1} and 23 (mmol $l^{-1})^{1/2}$, respectively, revealing the experimental soil as saline-sodic (Ghafoor *et al*. 2004).

Amendments & soil substrate

Analysing and characterizing of the soil and amendments were performed prior to the beginning of the experiment. Biochar rice husk residue (from a rice field in Isfahan) was produced in a pyrolysis chamber at a temperature of approx. 300°C. The slow pyrolysis process was applied consisting in a gradual increase of the temperature with 2°C min^{-1} to the desired heat while a continuous inflow of inert gas (nitrogen) to the chamber. The municipal solid waste compost was brought from Isfahan Municipal Waste Management field. More than 99% of the solid waste was made up of municipal solid wastes with almost 72.5% of organic matter (OWRC 2010). The other materials included rubber and plastic (17%) as well as metals (0.4%) (Abduli *et al*. 2013). The composted fertilizer was produced industrially by the Isfahan Recycling Organization. The production process included feeding, sorting, crushing, fermentation, and, finally, drying and packaging. The two organic amendments of urban municipal solid waste compost (C) and rice husk biochar (B) as the substrates were air-dried, ground to pass through a 2-mm sieve and thoroughly mixed and poured to the 3-kg experimental pots.

Table 1. Some characteristics of soil, amendments and substrates

Property	Units	Soil	Biochar	Municipal solid waste compost	BT	CT	BCT
pH (1:5)	-	8	6.7	7.5	7.5	7.5	7.6
ECe (1:5)	dS m^{-1}	14	0.4	5	11.9	12.9	12.1
K^+	mmol l^{-1}	0.39	1.5	3	0.35	0.47	0.4
SOC	%	0.6	23.2	18.5	0.64	0.62	0.62
Na	mmol l^{-1}	121.02	0.23	6.3	100	107	108
Mg	mmol l^{-1}	16.08	2.8	4	15.6	15.5	15.3
Ca	mmol l^{-1}	11.6	4.9	36.5	10.6	11.5	11
SAR	-	23	-	-	19.2	20.6	21.1
Bulk density	g cm^{-3}	1.16	0.24	0.52	1.05	1.18	1.07

BT: biochar treatment at a rate of 1.5% w/w, CT: municipal solid waste compost treatment at a rate of 1.5% w/w, BCT: combination of B and C treatment at a rate of 0.5 × 0.5% w/w.

The packing was performed as to reach desired bulk densities (Table 1). Selected properties of soil, substrates and the amended soils are presented in Table 1.

Experiment layout and treatments

We used a completely randomized design with three factorial arrangements and three replications for each treatment. The natural saline water was diluted with a certain amount of NaCl for preparing the 4.5 and 9 dS m^{-1} watering treatments. Tap water was used as the control. The pots were irrigated at 0.15 leaching fractions (LF) and the soil electrical conductivity (ECe) was equilibrated as: ECe = 1.5 × ECw.

Treatments contained biochar (BT), municipal solid waste compost (CT), a mixture of biochar and BCT and the control with soil alone. The experiment was carried out in the greenhouses of Isfahan University of Technology, College of Agriculture. Three kg of the amended soils were poured in plastic pots with 3 replications. The bottom of each pot was filled with 5-cm course gravels to act as a filter drain. The pots were stored in the greenhouse for one month with water content close to the field capacity and at a temperature of 20±1°C. The sorghum seeds (Sepideh genotype) were planted at a depth of 2.5 cm in each pot. After planting, the pots were watered with tap water for the control treatments and the other treatments with 4.5 dS m^{-1} salinity solution. After the germination, the 9 dS m^{-1} treatment pots were irrigated with the natural saline water, until to the end of the experiment. During the plant growing period and with about 30% of the available water used, irrigation was applied for all the pots, obtaining 15% of the leaching fraction (Alizadeh 2002).

Soil analysis

To obtain the chemical properties, soil samples were collected during the experiment from each pot at two different periods; two months (T1) and three months (T2) after the sowing (at the third and fifth leaf stage of the growing period, respectively). Soil saturation paste extract of ECe, Ca^{+2} and Mg^{+2} were measured using atomic absorption spectroscopy and Na^{+1} – by the flame photometer (Chapman and Pratt 1962). Organic carbon was determined by the wet digestion method (Walkley and Black 1934). Sodium adsorption ratio (SAR) was calculated using the following formula: $SAR = (Na^{+} / (Ca^{+2} + Mg^{+2})^{0.5}$.

Plant analysis

Plant samples were collected at the two periods (T1 and T2) for determining leaf water potential, chlorophyll content and proline accumulation. Samples were taken from each pot, in the middle of the day.

Leaf water potential (LWP)

Leaf water potential (LWP) as the whole plant water status (Pantuwan *et al.* 2002) was carried out using a pressure chamber according to the technique described by Scholander *et al.* (1965). Leaves were cut in the middle of the day (12:00–14:00) and were wrapped in plastic bags and immediately taken to the laboratory. Then the leaves were sealed in the chamber so that the cut end of the petiole exposed to atmosphere and pressure (nitrogen gas) was applied into the chamber until the sap appeared. Three repetitions for each pot were performed and the arithmetic mean of the three readings was considered as the leaf water potential value.

Chlorophyll

The chlorophyll of the leaves was determined with the Arnon (1949) method, at the end of the experiment. For this, 0.2 g of leaf from each plant was ground with liquid nitrogen and the extract volume was increased to 10 ml by adding 80% acetone, followed by centrifugation at 3,000 rev/min for 10 min. To estimate the *a* and *b* chlorophyll contents, the solution absorption was measured at 663 and 645 nm using a spectrophotometer. Arnon (1949) gave the equations for extraction with 80% acetone and absorbance read at 645 nm and 663 nm as follows:

$$\text{Chlorophyll } a\ (\mu\text{g/ml}) = 12.7\ (A663) - 2.69\ (A645)$$

$$\text{Chlorophyll } b\ (\mu\text{g/ml}) = 22.9\ (A645) - 4.68\ (A663)$$

$$\text{Total chlorophyll } (\mu\text{g/ml}) = 20.2\ (A645) + 8.02\ (A663)$$

Proline

The proline content is the most widely adopted compatible osmolyte characteristics among the plants; the intracellular leaf level of this amino acid was therefore measured at the end of the two periods of measurement (T1 and T2). Proline content in the leaf tissues was extracted and analysed according to the method of Bates *et al.* (1973). For that, 0.5 g of fresh leaf materials were ground in a mortar with liquid nitrogen, then extracted with 3% sulfosalicylic acid. The extract was heated in a water bath for 10 min and then filtered through filter paper. Two ml of the extract was mixed into 6 ml assay media containing 2 ml ninhydrin solution and 2 ml acetic acid. After that, all samples were incubated at 90°C for 60 min and cooled to room temperature. The coloured product was extracted by adding 4 ml toluene. Finally, the absorbance of the organic layer was measured at 520 nm (Bates *et al.* 1973).

Statistical analyses

Statistical analyses of the recorded data were performed based on a completely randomized design with factorial arrangement and three replicates. The means of the experimental treatments were compared using the least significant differences (LSD) test at the 0.01 and 0.05 probability levels. All of the data were analysed using the SAS package (SAS 2015).

RESULTS AND DISCUSSION

The results of the analysis of variance (ANOVA) of soil chemical and plant physiological properties are shown in Table 2. Most of the main effects and interactions were significant for the measured properties. The following sections separately bring the statistical analysis for the soil and plant properties.

Table 2. Analysis of variance of the measured soil chemical and plant physiological properties

Source of variation	df	Mean Square					
		ECe	SAR	SOC	LWP	Chlorophyll	Proline
Time	1	22.17**	5033.72**	0.06**	49.17**	35.95^{ns}	701.62**
Salinity	2	43.97**	923.16**	0.25**	26.09**	1068.7**	331.74**
Amendment	3	5.55**	45.94*	0.018**	22.73**	65.80^{ns}	2.62^{ns}
Time × Salinity	2	3.93**	909.9**	0.066**	39.68**	12.99^{ns}	269.19**
Time × Amendment	3	0.34^{ns}	48.72*	0.001^{ns}	35.64**	45.45^{ns}	8.73**
Amendment × Salinity	6	0.28^{ns}	122.007**	0.017**	15.25**	291.01**	3.42*
Time × Amendment × Salinity	6	1.50**	137.9**	0.0035*	31.66**	212.38**	6.38**
Error	24	0.27	12.87	0.0018	2.88	41.87	1.12

**,* respectively stand for the significant effects at ($p < 0.01$) and ($p < 0.05$) probability level, ns = not significant, df: degree of freedom, ECe: electrical conductivity, SAR: sodium adsorption ratio, SOC: soil organic carbon and LWP: leaf water potential.

Soil properties

The results of soil chemical properties changed by the treatments and for the two different periods of measurement (T1 and T2) are described in the sections below.

Electrical conductivity (ECe)

More salt in the irrigation water significantly ($p < 0.01$) increased the amounts of soil ECe (Table 3), but longer irrigating time resulted in lower amounts of ECe (comparing T2 with T1). The ECe significantly decreased by biochar application (BT) throughout the experiment, when compared to the control (non-amended soil). Applying biochar resulted in reducing ECe by almost 7.5% and 6.4% for T1 and T2, respectively, compared to the control. Chaganti *et al*. (2015) reported some 84% decrease in ECe of a saline-sodic soil as a result of biochar application. The possible reason may be the improvement in soil hydraulic properties (conductivity) and porosity that facilitate the leaching of salts (Chaganti *et al*. 2015) and adsorption elements, causing salinity (such as Na^+) on the biochar surfaces (Akhtar *et al.* 2015a). The application of biochar proved to be effective in reducing the salinity stress by improving soil properties directly related to Na^+ removal. This might be through processes such as Na^+ leaching, Na^+ adsorption, and decreasing the EC (Chaganti *et al.* 2015, Rekaby *et al*. 2021).

At T1, the ECe value of the CT increased by 5%, while the slight increase was observed at T2, compared with the control and the BCT treatment (Table 3). The higher amounts of soil electrical conductivity for the CT and BCT, compared to the other treatments could be due to the high ECe value in their original soil (14 dS m^{-1}) and (5 dS m^{-1} for CT).

Table 3. Mean comparisons of some soil chemical properties for treatments interactions

		ECe		SAR		SOC	
		T1	T2	T1	T2	T1	T2
Irrigation water salinity	Tap water	11.0 d	9.0 e	25.09 c	16.94 d	0.83 c	0.66 d
	4.5 (dS m^{-1})	12.1 b	11.5 c	29.84 b	18.66 d	0.84 c	0.89 b
	9 (dS m^{-1})	13.03 a	12.3 b	48.42 a	17.58 d	0.97 a	0.93 ab
Amendment	Non	12.0 b	11.0 c	30.85 c	16.63 d	0.83 cd	0.79 d
	BT	11.1 c	10.3 d	34.57 b	18.12 d	0.92 a	0.87 b
	CT	12.6 a	11.3 c	33.72 bc	17.65 d	0.90 ab	0.85 c
	BCT	12.4 ab	11.1 c	38.67 a	17.50 d	0.88 b	0.81 cd

* data in each column with similar letters are not significantly different at $p = 0.05$. T1: two months after sowing, T2: three months after sowing, Non: control without amendment, BT: biochar treatment at a rate of 1.5% w/w, CT: municipal solid waste compost treatment at a rate of 1.5% w/w, BCT: combination of B and C treatment at a rate of 0.5 × 0.5% w/w.

Sodium adsorption ratio (SAR)

A clear nearly twofold increase in the SAR value was observed under applied saline irrigation water (48.5 compared to 25, respectively for the 9 dS m^{-1} treatment and tap water). This is due to the increased concentration of sodium Na^+ in the 9 dS m^{-1} treatment. The salinity level at 9 dS m^{-1} caused an increase in SAR by 46% at T1 and 3.6% at T2 compared to tap water (Table 3). Salinity irrigation water average decreased SAR about 45% at T2 when compared to T1. Organic amendments significantly increased the amounts of

SAR in the first period of the experiment. The amount of increase in the SAR at the T1 sampling was not significantly different when compared to CT with BT and the control treatments. However, the amount of SAR showed a significant difference between BCT and BT treatment of the T1 period (Table 3). This probably is because of the high concentration of Ca^{+2} in the municipal solid waste compost which caused significant decrease of the SAR in the first period of the measurement (T1). Leogrande *et al*. (2016) reported that addition of municipal solid waste compost into a sodic water irrigated soil, enriched the rhizosphere with nutrient elements, and hence reduced SAR. During the second period of sampling (T2), this effect disappeared gradually. However, at T2, the application of amendments had identical impacts on SAR of all of the treatments, and overall showed lower values comparing to the T1 period. This might be due to the mineral weathering and leaching out sodium from the soil (Leogrande *et al*. 2016).

Soil organic carbon (SOC)

Soil organic carbon content was significantly influenced ($p < 0.01$) by almost all the treatments (Table 2). Results indicated that SOC was increased as the salinity level grew in both periods of measurements. At the first period of measurement (T1) and for the 9 dS m^{-1} treatment numerically (non-significant different) higher amount of SOC was shown compared to the other treatments (Table 3). This is in agreement with Wong *et al*. (2009) who found that applying organic amendment into a highly saline-sodic soil increased the initial microbial respiration and consequently resulted in higher decomposition rates of dissolved organic carbon. However, at the second period of measurement no differences were seen between the salinity water treatments and the control. This corresponds with the findings of Setia *et al*. (2013) who reported that high soil salinity caused a decrease in microbial activity and consequently slower decomposition rates of dissolved organic carbon.

Applying the amendment along with salinity and time significantly ($p < 0.05$ and $p < 0.01$) altered SOC content in this experiment (Table 2). Irrigation salinity caused almost a 5.5% reduction in SOC content when T2 is compared to T1 (Table 3).

Plant parameters

Means comparisons of some of the physiological properties of the plant (leaf water potential, and chlorophyll and proline content) that responded to salinity stress and amendments are shown in Table 4. The results and descriptions for these properties are separately mentioned in the sections below.

Table 4. Mean comparisons of the measured plant parameters

		Leaf water potential		Proline		Chlorophyll	
		T1	T2	T1	T2	T1	T2
Irrigation water salinity	Tap water	20.08 c*	22.87 b	0.43 d	2.36 c	27.38 a	24.38 ab
	4.5 (dS m^{-1})	20.87 c	24.33 a	0.96 d	3.79 b	19.99 b	19.90 a
	9 (dS m^{-1})	24.20 ab	22.9 b	1.29 d	15.25 a	13.13 c	11.98 c
Amendment	Non	20.94 c	25.66 a	0.89 c	7.20 ab	24.34 a	20.28 ab
	BT	23.33 b	22.05 bc	0.76 d	7.04 b	19.96 ab	16.00 b
	CT	23.33 b	23.22 b	1.31 c	7.43 a	19 ab	19.55 ab
	BCT	19.27 d	22.04 bc	0.91 c	7.33 a	17.35 b	19.38 ab

* data in each column with similar letters are not significantly different at $p = 0.05$. T1: two months after sowing, T2: three months after sowing, Non: control without amendment, BT: biochar treatment at a rate of 1.5% w/w, CT: municipal solid waste compost treatment at a rate of 1.5% w/w, BCT: combination of B and C treatment at a rate of 0.5 × 0.5% w/w.

Leaf water potential (LWP)

Results of analysis of variance showed that irrigation with saline water at the three salinity levels resulted in a decrease in leaf water potential (became more negative). When plants are subjected to soil solution salinity, higher water salinity level caused less LWP. The interactive effects between the irrigation water and the amendments on LWP and between the amendments and the sampling periods were also significant ($p < 0.01$) (Table 2). The combination of B and C treatment (BCT) showed significantly higher amount of LWP in two periods, 7.6% for T1 and 14% for T2 compared to the control.

However, in both periods of measurements, LWP showed no differences between the BT and CT treatments. At the second time of the sampling period, all of the three treatments had a lower amount of LWP compared to the control (Table 4), revealing that applying biochar and compost in a long time is easing the salinity stress and improved the plant water status, as it showed a lower negative LWP value compared to untreated treatments (Non). Similar results were found by Kanwal *et al.* (2018), who reported the maximum increase of 16% in LWP for the 2% biochar application and soil with 150 mM salt. For the CT treatment the amount of LWP during the T1 period was increased. This is in agreement with Leogrande *et al.* (2016) who found that incorporating compost in to saline irrigation would enhance the salt tolerance and growth of crops.

Proline

Proline is known to be a highly concentrated endogenous substance that accumulates in the salt stressed plants at the low water potential caused by drought or salinity. It has been considered as one of the osmotic stress indexes and the effective indicators for salt tolerance plants (Ashraf and Foolad 2007, Szabados and Savouré 2010). The irrigation with saline water at different levels resulted in the increase in proline leaf content for the T1 and T2 periods of measurements (Table 4). The highest amount of proline content was observed for the 9 dS m^{-1} salinity level with about seven times higher as compared to the control. No significant differences for proline content were obtained between the treatments at the first sampling period of measurement (T1) (Table 4). The greatest accumulation of proline at the second sampling time (T2) was observed for the biochar (BT) and combination (BCT) treatments with no significant difference with the corresponding control. Proline may play a protective role against the osmotic potential generated by salt. Proline concentration in the CT treatment was higher compared to all other treatments ($p < 0.05$), and increased by almost 32% when compared to control (Table 4). This could probably be due to the adverse effects of municipal solid waste compost on some of the soil physio-chemical properties. Many studies have shown that the accumulation of proline in leaves of sorghum and rice cultivated under salt condition is the primary defending response to maintain the osmotic adjustment in plant cells (de Lacerda *et al*. 2003, 2005, Demiral and Türkan 2005).

Chlorophyll

Chlorophyll is a green pigment widely distributed in plant leaves, with a high sensitivity to salt exposure. The results of this study revealed that as the irrigation water salinity levels increased, the leaf chlorophyll content significantly decreased (Table 4). The chlorophyll contents at the two sampling periods did not exhibit significant differences in all soil amendment treatments, compared with the corresponding control values (Table 4). At T1, there was registered the lowest amount of chlorophyll content for BCT (28.7% decrease compared to tap water), while no significant differences between BT and CT were observed. At T2, the BT had the lowest amount for chlorophyll content (Table 4). Munns and Tester (2008) reported that plant growth suppress under saline condtion may be due to the osmotic reduction in water availability. Iqbal *et al*. (2006) reported that production rates of chlorophylls *a* and *b* decreased in a salinity stress condition, because of the salinity-induced enzymatic activity. They also noted that the reduction in chlorophyll production rate probably is due to the change in nitrogen metabolism direction during the formation of compounds such as proline which are used in regulating osmoses (Krishnamurthy *et al*. 2003, Cakmak and Kirkby 2007). Other causes for this reduction is the formation of proteolytic enzymes, responsible for decomposing chlorophyll and damaging photosynthetic structure (Cakmak and Kirkby 2007). On the contrary, some results indicated that chlorophyll content may be improved by biochar application under salinity stress (Farhangi-Abriz and Torabian 2018). Akhtar *et al*. (2015b) reported that the application of biochar elevates the photosynthesis rate, and this caused an increase in the chlorophyll content (Akhtar *et al*. 2015b). This is in contrast to our findings regarding the effects of biochar application on the chlorophyll content.

CONCLUSIONS

1. Irrigation water salinity had a negative influence on the chemical properties of soil salinity, whereas application of soil amendments had a positive effect. As the salinity level of the irrigation water increased, the amounts of ECe, SAR and SOC increased as well. Adding of amendments into the soil caused a decrease in electrical conductivity for both periods, compared with the control. Biochar resulted in the lowest value of electrical conductivity for all of the treatments. The SAR at the second sampling time (T2) declined significantly as compared with the first sampling (T1). In total, biochar application under saline soil had high positive impacts on soil properties (compared with other treatments) with decreased ECe and SAR and increased SOC in both periods.

2. The physiological characteristics of the sorghum plant were affected by both irrigation water salinity and application of soil amendments. Leaf water potential and proline content increased as the salinity level of irrigation water rose, while the cell chlorophyll content decreased. Applying the amendments caused an increase in LWP in the T2 period compared with T1, while no significant changes for the leaf chlorophyll content was observed between the two sampling periods. The plant cell proline content was greatly affected by the applied amendments and increased in the T2 period compared to the T1 sampling time. The compost treatment had the highest amount of the plant cell proline content.

3. Since the studied soil is basically high in salt and low in organic matter content, application of proper amendments with higher reclamation effects could be a sustainable solution to the land reclamation and farmers' urgent needs for agricultural production. Biochar (B), relatively to the other treatments with more proper characteristics (i.e. improving soil properties), might be an appropriate recommendation to the region.

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