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Use of biochar for alleviating negative impact of salinity stress in corn grown in arid soil

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Abstract

Tremendous benefits of biochar (BC) amendment to soil have been reported, including their role in alleviating the impact of salinity stress in plants. The aim of this study was to evaluate the effects of BC produced at 300 °C (BC300) and 700 °C (BC700) on the germination rate (GR) and selected growth characteristics of corn plant irrigated with salinized water over a growth period of six weeks. The experimental treatments included: three biochar treatments [BC0 (control, without biochar addition), BC300 and BC700] and three salinity levels of irrigation water [0, 3, and 6 dS m⁻¹]. The biochar was applied at a rate of 3%. The GR decreased with increasing salinity level, which was more evident in the first week. This stress impact was reduced when treated with the BC700 relative to the saline treatments without BC. Both BCs demonstrated contrasting effects on corn growth, nutrient uptake, and Na⁺ and K⁺ content in plant tissue. The effect of BC700 treatment on plant height and root length was limited, but the impact of salinity stress on chlorophyll meter readings, chlorophyll fluorescence parameter (Fv/Fm), dry matter yield, and N and P uptake were largely mitigated. It also increased K⁺ and decreased Na⁺ content in plant tissue. However, the BC300 treatment adversely affected plant growth parameters at each salinity level. Overall, the BC produced at a higher temperature significantly alleviated the impact of salinity stress on plant growth characteristics, which is probably attributed to their higher surface area and porosity, enhancing their salt ion sorption capacity.

Keywords: biochar, saline irrigation, salinity stress, irrigation, germination rate, chlorophyll meter readings, corn growth, arid soil, nutrient

Introduction

Salinity, one of the major abiotic stresses, is a serious global issue that endangers agricultural sustainability and food security. Soil degradation via salt accumulation and the use of low-quality water has reduced the size of cultivated areas worldwide. Approximately, one billion hectares of land worldwide are reportedly affected by salinity, which is expected to expand in the future due to poor water quality and management practices (Tóth et al. 2008; Wong et al. 2010). This phenomenon is dominant in irrigated agricultural lands specifically in arid and semi-arid regions due to low rainfall, high evaporation and transpiration rates, low irrigation water quality, and improper management practices (Sameni and Morshedi 2000; Parida and Das 2005; Shrivastava and Kumar, 2015). Additionally, water shortage in arid and semi-arid regions has caused a continual increase in the use of saline water for irrigation, exacerbating the salinity problem, which may have adverse impact on the crop productions in long run in these regions (Ahmed et al. 2012; She et al. 2018). Increased salt concentration in the soil creates stress conditions, which suppress plant growth by imposing osmotic stress, ion toxicity, and nutrient imbalances (Munns and Tester 2008; Parihar et al. 2015). This ultimately results in a significant reduction in crop yield, affecting agricultural productivity and causing an economic loss (Parihar et al. 2015; Ali et al. 2017). Considering the growing world population and increasing food demand, seeking an effective method to mitigate the impact of salinity on crop production is imperative, which includes the applications of organic amendments.

Various type of organic materials such as compost, animal manure, poultry litter, and crop residues have been frequently evaluated for their use in mitigating the impact of salinity on crop growth (Tejada et al., 2006; Walker and Bernal 2008; Lakhdar et al. 2009; Wang et al. 2014; Oo et al. 2015; Xie et al. 2017; Gao et al. 2019; Meena et al. 2019). These organic amendments improve soil physical, chemical, and biological properties, thereby promoting plant growth under

saline conditions (Walker and Bernal 2008; Dahlawi et al. 2018). Their benefits also include the supply of nutrients, such as Ca^{2+} and Mg^{2+} that compete with Na^+ , decreasing its proportion in the exchange sites and promoting its removal from the rhizosphere via leaching process (Walker and Bernal 2008; Dahlawi et al. 2018; Meena et al. 2019). However, certain organic amendments may contain high concentration of soluble salts, and their use can aggravate salinity (Hao and Chang, 2003; Gondek et al. 2020). In addition, most common organic amendments have a high rate of decomposition, and their frequent application may contribute to environmental pollution through increasing CO_2 emission, especially under arid agricultural systems, where high temperature accelerates decomposition (Thangarajan et al. 2013). Converting the organic materials into biochar, and their use in mitigating the adverse impact of salinity may be a feasible option for sustainable agriculture.

Biochar, a product of thermal degradation of organic materials in the absence of or under limited oxygen conditions, has been perceived as a promising soil amendment (Lehmann 2007; Lehmann et al. 2011; El-Najjar et al. 2019). Numerous benefits of its agricultural and environmental applications have been reported, including enhancement of soil properties, crop production, mitigation of greenhouse gas emissions, and environmental remediation (Blanco-Canqui 2017; El-Najjar et al. 2019; Cayuela et al. 2014; Yang et al. 2017; Zhang et al. 2021; Xie et al. 2015). However, the extent of its effectiveness largely varies according to its characteristics, which are driven by their production conditions, such as pyrolysis temperature, residence time, and the feedstock type (Kloss et al. 2012; Tomczyk et al. 2020; Atkinson et al. 2010; Gul et al. 2015).

The application of biochar in alleviating salinity stress on plant growth has recently emerged as another viable option for sustainable agriculture (Ali et al. 2017; Dahlawi et al. 2018; Tan et al.

2021). Overall, most studies reported that biochar improved the plant germination rate and growth characteristics under saline conditions (e.g. Thomas et al. 2013; Akhtar et al. 2015; She et al. 2018; Farhangi-Abriz and Torabian, 2018; Huang et al. 2019; Rezaie et al. 2019; Ibrahim et al. 2020; Xiao et al. 2020). Besides feedstock type, pyrolysis temperature is another major factor that largely influences the physical and chemical properties of biochar, and thereby its performance as a soil amendment and its other uses, including salinity stress mitigation (Lehmann 2007; Tomczyk et al. 2020). For instance, biochar surface area and porosity increases with increasing pyrolysis temperature, which enhances its adsorption and retention capacity, thereby reducing plant Na^+ availability (Lehmann 2007; Antonangelo et al. 2019; Thomas et al. 2013; Akhtar et al. 2015). However, the magnitude of biochar effect in reducing salinity stress on plant growth and development widely vary, which depend on salinity level, biochar characteristics, soil type, and species (Thomas et al. 2013; Dahlawi et al. 2018; Xiao et al. 2020; Tan et al. 2021). Further studies are required to verify the potential use of biochar in alleviating the adverse effect of salinity on plant growth, especially under arid soil conditions, where several productivity constraints exist, such as alkalinity, high content of CaCO_3 , and poor content of organic matter and nutrient. Therefore, the objective of this study was to investigate the effect of two types of biochar produced from feather meal at 300 °C and 700 °C on corn (*Zea mays* L.) germination and selected growth characteristics in arid soil irrigated with three levels of salinity (0, 3, and 6 dS m^{-1}). Hypothetically, high temperature biochar can improve plant germination and growth by mitigating the adverse impact of salinity through its higher sorption capacity. Furthermore, the reasons for selecting corn as a test crop in this study include: 1) corn is ranked as the third most cultivated cereal crop worldwide, 2) it is grown under a wide range of environmental and soil conditions, and 3) it is

classified as moderately sensitive to salinity stress (Maas et al. 1983; Khodarahpour et al. 2012; Farooq et al. 2015).

Materials and methods

Study soil and biochar preparation

Soil used in this study was collected from an abandoned site of a private farm located near Thadiq city (25°16'45.1" N, 45°52'52.2" E), northwest of Riyadh, Saudi Arabia. This site was uncultivated for approximately 8 years. A composite sample was collected from a depth of 0–20 cm, air-dried, and sieved through 2 mm mesh, following which the soil was analyzed for its basic characteristics. Soil pH and electrical conductivity (EC) were measured at a ratio of 1:2.5 in soil/distilled water suspension, and observed values were 8.1 and 0.17 dS m⁻¹, respectively. Soil contained 0.39% organic matter and 22.2% CaCO₃, which were analyzed following the method described by Nelson and Sommers (1996) and Loeppert and Suarez (1996), respectively. The particle size was analyzed according to the method described by Gee and Bauder (1986). The soil contains 86.9%, 6.0%, and 7.0% of sand, silt, and clay, respectively.

Biochar (BC) was produced from feather meal, a byproduct of poultry processing industry, which was used as a feedstock at two pyrolysis temperatures: 300 and 700 °C, represented as BC300 and BC700, respectively. Feather meal, rich in carbon and nutrient, is locally abundant, and its conversion into biochar may be an alternative to a sustainable approach. The feather meal was transferred to a tightly closed chamber to ensure oxygen-free environment, placed in a muffle furnace and pyrolyzed at the desired temperatures for 3 h. The produced biochar was ground and sieved through 1.0 mm mesh, and analyzed for its basic characteristics, as listed in Table 1.

Experimental setup

The experimental design included nine treatments, consisting of three biochar treatments and three salinity levels of irrigation water. The biochar treatments were no biochar (BC0), BC300, and BC700 applied at a rate of 3% (w/w), whereas the salinity treatments were non-saline (0 dS m⁻¹), 3, and 6 dS m⁻¹. The considered biochar application rate is within the range reported in the literature to demonstrate the effective use of biochar (Jeffery et al. 2011; Semida et al. 2019). The biochar was mixed thoroughly with 1 kg air-dried soil and placed in a plastic pot ($d = 12$ cm, $v = 1000$ cm³), which was individually supplemented with mineral fertilizers at a rate of 300 kg N, 200 kg P, and 100 kg K ha⁻¹. Treatments were replicated thrice. The soil-biochar mixture was equilibrated for 24 h, after which six corn (*Zea mays* L.) seeds were sown in each pot. Soil moisture maintained at 80% of field capacity throughout the study period was monitored regularly by weight loss, and supplemented with water when required. Saline water irrigation started immediately after sowing and continued throughout the study period of six weeks. Saline water used for irrigation was prepared by salinizing tap water with NaCl, and the target salinity level was checked using an EC meter. The study was conducted under greenhouse conditions with temperature maintained at 23–25 °C.

Plant growth characteristics and measurements

Germination rate (GR), calculated as the percentage of number of seed germinated to the total seeds sown, was recorded weekly (up to three weeks), after which the corn plants were thinned to only three plants per pot. After six weeks of growth, the chlorophyll fluorescence parameter, relative chlorophyll content, plant height, and root length were measured. Roots were gently separated from soil, and root length of the three plants per pot was individually measured with a ruler and averaged, which was subsequently used for data analysis. Chlorophyll fluorescence parameter was measured using a portable chlorophyll fluorometer (Handy PEA,

Hansatech Instruments Ltd, Norfolk, UK), and the ratio of variable to maximum fluorescence (F_v/F_m) was determined as described by Maxwell and Johnson (2000). Leaf chlorophyll content, referred to as chlorophyll meter readings (CMR), was measured using a SPAD meter. The aboveground biomass was weighed after oven-drying at 60 °C for 72 h to determine the dry matter yield. A subsample of the plant dry matter was finely ground and acid-digested as described by Thomas et al. (1976), followed by N, P, K and Na determination. The N was determined using kjeldahal method as described by Jones (1991), whereas the P was colorimetrically determined using the method described by Murphy and Riley (1962). Furthermore, K and Na were determined using a flame photometer.

Statistical analysis

Data collected from the study were subjected to a one-way ANOVA to test the responses of plant parameters to treatment. Treatment effects were declared significant at $P < 0.05$, where the treatment means were separated using the Student-Newman-Keuls (SNK) test. The CoStat software (CoHort Software, 2008) was employed to perform the statistical analysis.

Results

Effects on germination rate

The germination rate (GR) of corn seeds recorded weekly up to three weeks after sowing are shown in Fig. 1. The impact of salinity stress on the GR was more evident in the first week, which was severe at higher water salinity level (6 dS m⁻¹), where the GR significantly reduced by 42% compared to the control (Fig. 1). The GR observed a significant decrease with increasing salinity level, with 100%, 78%, and 58% for 0, 3, and 6 dS m⁻¹ treatments, respectively. The BC300 treatment significantly reduced the GR at any salinity level and provided the least value among the other treatments, ranging from 42 to 47%. The BC700 treatment presented a similar effect on

GR at salinity level of 3 dS m⁻¹, whereas it demonstrated higher GR at 6 dS m⁻¹ compared to BC0 treatment. In general, the GR was delayed up to the second week, where a higher GR is significant; however, the response effects to salinity levels and BC treatments practically followed a similar pattern to that in the first week (Fig. 1), with the lowest GR percentage being observed in the absence of biochar at salinity level of 6 dS m⁻¹. In addition, the BC700 continued to exhibit higher GR during the second week at salinity level of 6 dS m⁻¹ compared to BC0 treatment. At week three, the treatment effect patterns remained almost identical, with the BC700 supporting higher GR at salinity level of 6 dS m⁻¹ compared to BC0 (Fig. 1). The GR percentage obtained from BC700 treatment was similar to that observed in BC0 treatment at salinity level of 0 dS m⁻¹. The BC300 treatment was the least effective at any salinity level during the entire germination study period (Fig. 1).

Effects on plant growth parameters

Plant height was significantly affected by salinity stress and was reduced at increasing salinity level, with the value of 37, 27 and 20 cm being recorded under 0, 3 and 6 dS m⁻¹ saline irrigation, respectively (Fig. 2a). Both 3 and 6 dS m⁻¹ treatments reduced the plant height by 28% and 47%, respectively, when compared to the control (Fig. 2a). None of the biochar treatments (BC300 and BC700) alleviated salinity stress impact on plant height compared to the control. However, the BC300 significantly reduced the plant height under all salinity levels, which was considerably pronounced when combined with 3 and 6 dS m⁻¹ treatments (Fig. 2a). The BC700 addition displayed statistically higher plant height values to that observed with the BC300 at all salinity levels. At salinity level of 6 dS m⁻¹, the BC700 treatment showed significantly higher plant height compared to the BC0 treatment (Fig. 2a).

Root length was also significantly influenced by salinity stress and biochar addition (Fig. 2b). The highest values of root length were recorded in the absence of saline water, in both the control and BC700 treatments, and were significantly higher than any other treatment. Furthermore, BC700 did not increase the root length at any salinity level, whereas BC300 significantly reduced the root length by 65%, 71%, and 69% at salinity levels of 0, 3, and 6 dS m⁻¹, respectively (Fig. 2b).

Chlorophyll meter readings (CMR) recorded one month after sowing ranged from 7.3 to 23.5 (Fig. 2c), and were significantly affected by salinity, particularly at 6 dS m⁻¹; however, at this level of salinity, CMR increased in the presence of BC700 (Fig. 2c). The lowest CMR were observed in BC300 treatment at any salinity level, which significantly differed from that recorded in the control.

Chlorophyll fluorescence (Fv/Fm) significantly decreased with increasing salinity levels in the absence of BC (Fig. 2d). BC300 reduced chlorophyll fluorescence (Fv/Fm) value at the considered salinity levels. Salinity level of 6 dS m⁻¹ with BC700 treatment increased chlorophyll fluorescence (Fv/Fm) value compared to that without BC700, but this increase did not significantly differ from that of the control (0 dS m⁻¹ treatment) (Fig. 2d).

Effects on dry matter yield and N and P uptake

Salinity and biochar addition significantly affected the aboveground dry matter yield (Fig. 3a). The corn yield significantly decreased with increasing salinity levels of irrigation water, reducing the yield by 35% and 61% at 3 and 6 dS m⁻¹, respectively, compared to the control. The salinity level of 6 dS m⁻¹ combined with BC700 treatment increased the yield compared to the treatment at same salinity level without BC; however, this increase was significantly lower than that of the control (Fig. 3a). The BC300 treatment significantly reduced the yield, irrespective of

the salinity levels. The plant N uptake was also substantially affected by salinity, which decreased with increasing salinity levels (Fig. 3b). Furthermore, both BC300 and BC700 treatments significantly decreased plant N uptake at all salinity levels compared to the control. However, at salinity level of 6 dS m⁻¹, BC700 had higher N uptake than the other biochar treatments, whereas BC300 observed a significant decrease in plant N uptake at any salinity level. Furthermore, the impact of salinity stress on plant P uptake followed a similar pattern as that of plant N uptake without BC, with the lowest P uptake observed at 6 dS m⁻¹ (Fig. 3c). However, BC700 treatment increased the P uptake at both salinity levels of 3 and 6 dS m⁻¹, whereas BC300 significantly reduced the P uptake at all salinity levels.

Effects on plant K⁺ and Na⁺

The plant K⁺ and Na⁺ content was significantly affected by the salinity levels of irrigation water and biochar addition (Fig. 4a and b). The content of K⁺ in plant tissue was the highest in the control (0 dS m⁻¹) and decreased with increasing salinity (Fig. 4a). At salinity level of 0 dS m⁻¹, both BC300 and BC700 treatments significantly decreased the K⁺ content. However, the BC700 treatment showed significantly higher content of K⁺ at 3 and 6 dS m⁻¹ compared to these salinity levels in absence of BC (Fig. 4a). Conversely, the Na⁺ in plant tissue increased with increasing salinity level, with a content of 6400, 15661, and 24496 mg kg⁻¹ at 0, 3, and 6 dS m⁻¹ in absence of BC, respectively (Fig. 4b). The BC300 presented a substantially higher Na⁺ content in plant tissue compared to the other biochar treatments at the salinity levels of 0 and 3 dS m⁻¹, while at 6 dS m⁻¹, the Na⁺ content did not significantly differ from that observed in without BC treatment. In contrast, the BC700 treatment significantly reduced the Na⁺ content in plant tissue at the salinity level of 3 and 6 dS m⁻¹ compared to BC0 treatment (Fig. 4b).

Discussion

Salinity stress negatively affects several morphological, physiological, and biochemical processes involved in plants and thereby, it negatively affects the plant growth and developmental (Parihar et al. 2015; Negrão et al. 2017). This ultimately results in significant reduction in crop biomass yield and quality, rendering salinity as a key constraint in the agricultural production systems (Vargas et al. 2018). The results of this study clearly presents the negative impacts of salinity stress on corn seed germination rate and plant growth and development. The apparent adverse effects of the salinity stress include: reduced and delayed germination, and decreased plant height, root length, CMR, chlorophyll fluorescence rate (F_v/F_m), dry matter yield, and plant N and P uptake. Salinity also decreased K^+ and increased Na^+ in plant tissue. This is consistent with other findings in which various plant growth characteristics were adversely affected under salinity conditions (Ibrahim et al. 2016; She et al. 2018; Hniličková et al. 2019; Ibrahim et al. 2020). However, the magnitude of impact varies according to crop species, salts concentration, soil type, and management practices. In this study, the detrimental effect of salinity stress was considerably evident at higher salinity levels of irrigation water.

Biochar has recently been suggested as a possible alternative for mitigating the impact of salinity on crop growth and development (Thomas et al. 2013; Akhtar et al. 2015; She et al. 2018; Farhangi-Abriz and Torabian, 2018; Huang et al. 2019; Rezaie et al. 2019; Ibrahim et al. 2020; Xiao et al. 2020). However, both biochars used in this study exhibited contrasting effects on most measured plant-related parameters, and none revealed clear effects in alleviating the impact of salinity stress relative to the control (0 dS m^{-1} and BC0 treatment). Under salinity conditions, the biochar produced at the high temperature (BC700) effectively improved the GR, plant height, CMR, chlorophyll fluorescence (F_v/F_m), corn dry matter yield, and N and P uptake. It evidently increased K^+ and decreased Na^+ content in the plant. This supports the hypothesis that BC700 can

be more effective in alleviating the negative impact of salinity on plant. In contrast, the biochar produced at low temperature (BC300) negatively impacted most of the measured plant parameters, either under non-saline or saline water treatments, leading to a significant reduction in GR, plant height, root length, CRM, chlorophyll fluorescence (F_v/F_m), dry matter yield, and N and P uptake. Variable effects of biochar on seed emergence and plant growth have frequently been reported, which is largely related to the feedstock type, pyrolysis temperature, application rate, plant species, and soil type (Semida et al. 2019; Furtado et al. 2016; Deenik et al. 2010; Kwapinski et al. 2010; Chan et al. 2008; Yamato et al. 2006). Under salinity conditions, biochar can improve plant growth via different mechanisms; either directly by supplying nutrients and reducing Na^+ availability by surface adsorption or entrapment in the pores of biochar, or indirectly by increasing water availability and enhancing several soil physical, chemical, and biological properties (Yu et al. 2019; Dahlawi et al. 2018; Palansooriya et al. 2019). In this study, ameliorating the salinity stress after adding biochar produced at 700 °C is highly likely related to adsorption or entrapment of Na^+ , reducing its availability to the plant. Biochar produced at higher temperature is highly porous and has a larger surface area (Lehmann 2007; Antonangelo et al. 2019). These characteristics possibly promote the adsorptive ability of the biochar used in this study, which is pyrolyzed at 700 °C to enhance its effectiveness in reducing the impact of salinity on plant growth. This is evident with the significant reduction in Na^+ content and the increase in K^+ content in plants treated with BC700. This supports the hypothesis that the high-temperature biochar has a higher sorptive capacity compared to the low-temperature one. Similarly, other studies reported improved plant performance under salinity conditions in the presence of biochar, which is attributed to the sorption of Na^+ by biochar, thereby reducing its absorption by the plant (Thomas et al. 2013; Akhtar et al. 2015; Rezaie et al. 2019).

In contrast, the low temperature biochar used in this study negatively impacted the plant growth and performance. This may be related to the high decomposability of this biochar, which provides additional energy to soil microbes, resulting in soil nutrient, especially N, to be immobilized, restricting plant growth and development. Biochar produced at low temperatures is less stable and has a higher content of labile components, stimulating microbial activities, and resulting in soil N immobilization (Zimmerman et al. 2011; Méndez et al. 2013; Nelissen et al. 2012). Alternatively, the inhibitory effect of BC300 treatment is possibly related to toxic compounds present in this specific biochar. Biochar produced at low temperature (e.g. 300 °C) may contain additional toxic components associated with their high content of volatile organic constituents (Zimmerman et al. 2011; Fernandes and Brooks, 2003; Spokas et al. 2010). Furthermore, biochar containing high volatile matter showed a detrimental effect on corn growth and N uptake with or without fertilizer, decreasing soil available N with higher microbial respiration, in comparison with biochar containing low volatile matter content (Deenik et al. 2010). These authors attributed the inhibition of corn growth mainly to N immobilization, with a possibility of phytotoxic effect. Similarly, this study also observed the adverse effects on corn growth and N uptake, with the application of low temperature biochar.

Conclusion

The effects of biochar on corn germination rate and growth characteristics varied and were highly dependent on the biochar type. The biochar produced at higher temperature (700 °C) was significantly effective in alleviating the impact of salinity stress on chlorophyll meter readings, chlorophyll fluorescence parameter (F_v/F_m), dry matter yield, and N and P uptake in higher salinity treatments. More importantly, this type of biochar clearly reduced Na^+ and increased K^+ content in plant tissue, which may explain its positive effects on corn yield and nutrient uptake

under salinity conditions. The mechanism by which the higher temperature biochar positively affects corn growth is likely related to its higher adsorptive capacity, due to its higher surface area and porosity. These characteristics are assumed to be responsible in reducing Na^+ availability to plant via surface adsorption or entrapment in biochar pores. However, lower temperature biochar used in this study had detrimental effects on corn growth characteristics at each salinity level. This is probably related to its higher content of volatile compounds, limiting N availability through immobilization, and the possibility of toxic substances present in this particular biochar, causing a phytotoxic effect. Further studies are necessary to determine the effects of biochar characteristics on its effectiveness in mitigating the impact of salinity stress on plant growth and to identify the possible mechanisms through which biochar can reduce salts availability for plant uptake.

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Table 1. Basic characteristics of the study biochars

Biochar	pH ^a	EC ^a	Total C ^b	Total N ^c	Total P ^c	BET surface area ^d
		ds m ⁻¹	%			m ² g ⁻¹
BC300	6.00	0.19	66.83	13.00	1.00	0.19
BC700	9.83	2.06	61.55	11.30	3.63	1.38

^apH and EC were determined in 1:10 BC:water suspension and its extract, respectively.
^bTotal carbon was measured using a CHNS analyzer (Series II, PerkinElmer, Waltham, MA, USA).
^cTotal N and P were measured colorimetrically after digestion in H₂SO₄-H₂O₂ (Thomas et al. 1967; Murphy and Riley 1962).
^dSurface area was analyzed following the method described by Toles et al. 1997.

Fig. 1. Effects of irrigation water salinity and biochar (BC) treatments (no BC added, BC0; BC produced at 300 °C, BC300; BC produced at 700 °C, BC700) on corn germination rate (GR) determined weekly for three weeks. The GR was statistically analyzed individually for each week. Error bars indicate the standard error of the treatment mean ($n=3$). Bars sharing the same letter are not significantly different according to SNK test at $P<0.05$.

Fig. 2. Effects of irrigation water salinity and biochar (BC) treatments (no BC added, BC0; BC produced at 300 °C, BC300; BC produced at 700 °C, BC700) on: a) plant height, b) root length, c) chlorophyll meter readings (CMR) and d) ratio of variable to maximum fluorescence (Fv/Fm). Error bars indicate the standard error of the treatment mean ($n=3$). Bars sharing the same letter are not significantly different according to SNK test at $P<0.05$.

Fig. 3. Effects of irrigation water salinity and biochar (BC) treatments (no BC added, BC0; BC produced at 300 °C, BC300; BC produced at 700 °C, BC700) on: a) corn dry matter, b) plant N uptake and c) plant P uptake. Error bars indicate the standard error of the treatment mean ($n=3$). Bars sharing the same letter are not significantly different according to SNK test at $P<0.05$.

Fig. 4. Effects of irrigation water salinity and biochar (BC) treatments (no BC added, BC0; BC produced at 300 °C, BC300; BC produced at 700 °C, BC700) on: a) plant K content and b) plant Na content. Error bars indicate the standard error of the treatment mean ($n=3$). Bars sharing the same letter are not significantly different according to SNK test at $P<0.05$.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.