



Influence of Biochar Amendment on Soil Water Characteristics and Crop Growth Enhancement Under Salinity Stress

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Abstract— Salinity is an important environmental constraint to crop productivity in arid and semi-arid regions of the world. Most crop plants, including tomato (*Lycopersicon esculentum* Mill), are sensitive to salinity throughout the ontogeny of the plant. Biochar was used in the present study to improve the available water content (AWC), growth, yield and irrigation water use efficiency of tomato plant under saline soil condition. The biochar was applied at the rates of, 0%, 2% and 4% w/w and expressed as Ck (control), T1 and T2, respectively. The experiment was conducted in the pots inside the greenhouse. The results showed that soil bulk density, field capacity, permanent wilting point, AWC, and soil organic matter were improved significantly as biochar application rate increased. Biochar application also enhanced plant height, stem diameter, plant fresh and dry weights and yield components of tomato plant. It was found that biochar application at T2 treatment in the whole growing period was best to improve tomato plant growth and yield, providing a biochar amendment recommendation for tomato production in field. Moreover, biochar application improved the irrigation water use efficiency. Therefore, biochar amendment could be an effective option to improve saline soil which affected croplands.

Keywords—Agriculture, Biochar, Bulk density, Growth, Irrigation, Saline soil, Yield.

I. INTRODUCTION

Salinity is a progressively vital environmental constraint to plant production worldwide [1]. Nevertheless of the cause (ion toxicity, water deficit, and/or nutritional imbalance), high salinity in the root zone severely impedes normal plant growth and development, resulting in reduced crop productivity or crop failure. A saline soil is generally defined as one in which the electrical conductivity (EC) of the saturation extract in the

root zone exceeds 4 dSm^{-1} at 25°C and has an exchangeable sodium percentage of 15. Of the total 14 billion ha of land available on earth 6.5 billion ha are estimated to be arid and semi-arid, of which about 1 billion are saline soils. Furthermore, it is estimated that about 20% of cultivated lands and 33% of irrigated agricultural lands worldwide are afflicted by high salinity [1, 2]. Moreover, the salinized areas are increasing at a rate of 10% annually; low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water, and poor cultural practices are among the major contributors to the increasing soil salinity.

Recently, Biochar has several sustainability achievements including improvements of soil and plant growth, energy production, and C sequestration. Furthermore, it can be produced as process heat, bio-oil, co-products like hydrogen, syngas, and liquid smoke via the pyrolysis process. In developing countries it's used as the implication of small stoves using for food processing could help to decrease the pressure on forests and reduce respiratory diseases [3, 4]. The annual soil application of agriculture residues is one of the management tools available for increasing soil organic matter content [5]. However, at the same time the demand for biomass for bioenergy production is growing, putting even more pressure on plant production and the utilization of agriculture and forestry residues [6].

Moreover, researches have also shown that biochar can improve crop growth either by its direct or indirect mechanism of engagements. The direct growth raise under biochar addition comprises supplying minerals nutrients, i.e. P, Mg, K, Ca, and S etc., to the plant whereas, indirect mechanism involves improving soil chemical, physical and biological features [7, 8]. Many studies have suggested that the effect of biochar is more pronounced in highly weathered, degraded and nutrient poor soils than in well-structured, nutrient rich and high quality soils [9, 10]. Additionally, biochar also received a great interest in remediating organic and inorganic contaminants due to its high adsorption capacity [11, 12]. The adsorption capacity of biochar is determined by the feedstock and production conditions [13].

The favorable adsorption attribute of biochar includes its properties of high cation exchange capacity (CEC) and surface area. Due to its high specific surface area, biochar has a significant adsorbing ability. Furthermore, may contribute to increasing the water holding capacity and plant-available water capacity of soil (AWC) due to its internal porosity [14, 15, 16 and 17]. An improvement in soil structure may be especially

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beneficial in coarse sandy soils showing high mechanical resistance to root growth due to low compressibility and high friction [18]. Consequently, the yield potentials of crops can generally not be fully exploited in coarse sandy soils. There are several researches conducted on the Biochar effects on plant growth ([19, 8]. Study carried out by Jeffery (2011) [20], which comprising of 177 individual studies revealed that positive effects of biochar incorporation into soils outbalance negative and neutral effects. According to the literatures, many researchers stated that the biochar addition positively reduces N₂O emissions from soil and nutrient leaching losses, suppress plant disease, improve plant growth, ameliorate soil acidity and stimulate soil microbial activity [21, 22].

Therefore, the aim of this study was to evaluate the effect of biochar on tomato plant performance under saline soil condition. Key elements of the crop and soil during the experiment were measured as defined in tables and figures below. The measurements included those made directly in the field alongside those measured in the laboratory using soil and biochar collected from the experiment.

II. MATERIAL AND METHODS

A. Experiment Setup

The experiment was conducted in a greenhouse from April to August 2014 at the Water Saving Park Agricultural Experimental Farm at Soil and Water Engineering Department at Hohai University in Nanjing, China. The farm is located at 31°95'N, 118°83'E, in a suburb of Nanjing at an area downstream of the Yangtze River drainage basin with an average elevation of 15 m above the sea level. This area is characterized by a humid subtropical climate and is under the influence of the East Asia Monsoon. The mean annual temperature is 15.5 °C, with monthly mean ranging from 2.4 to 27.8 °C; the highest temperature in this area is 43.0 °C while the lowest is -2.9 °C. The average annual rainfall is 1062 mm. The average temperature and humidity during the growing season inside the greenhouse are 30 °C and 79.75%, respectively. The soil at the experimental site is loam, Table 1 shows the physical and chemical properties of the soil used.

Table 1. Soil properties of the 0 - 0.2 m layer in the experiment site and biochar used

	Properties	
	Soil	Biochar
Bulk density (g/cm ³)	1.35	0.43
pH	8.6	9.9
EC (dS m ⁻¹)	1.45	1.0
OM (g kg ⁻¹)	2.75	803.58
Total N (g kg ⁻¹)	1.14	0.65
Texture	loam	loam

B. EXPERIMENTAL DESIGN

A randomized complete block design with three treatments [CK (no biochar, control), T1 (2% w/w biochar) and T2 (4% w/w biochar)], under three replications for each treatment was used. The biochar used was a commercial product produced from wheat straw, and pyrolyzed at 350–550°C in a vertical

kiln, manufactured by Sanli New Energy Company, Henan Province, China. Tomato (CV. Lycopersicon esculentum Mill, Yazhoufenwang) plant was used as the crop material which was transplanted on 14 April 2014 and harvested on 10 August 2014. The tomato seedlings were transplanted in the pots which were 42 cm in height with upper diameter of 30 cm and lower diameter of 25 cm. 21 kg of dry soil was put in each pot. Nine pots were used and each pot was filled with biochar and saline soil mixture. The experiment was designed with fully irrigation schedule 100% of the reference evapotranspiration (ET₀) for four stages of plant growth: seedling and establishment, flowering, fruit setting and fruit ripening stage. The irrigation water applied for each pot was 120 mm during the cropping season.

C. MEASUREMENTS

Soil properties were measured at the end of the season, bulk density (BD) was calculated as g cm⁻³ on dry weight basis, from the surface (0–20 cm) soil depth with three replicates from each pots. Soil electrical conductivity (EC) and pH were measured by using standard methods described by Tan, (2005) [23]. Soil organic matter (OM) was measured by the oil bath-K₂CrO₇ titration method Nelson (1996) [24]. Soil water content was measured gravimetric every seven days interval by auger. Available water content was measured by this formula (AWC = field capacity – permanent wilting point).

Plant growth was measured as plant height, stem diameter and dry matter. Data on plant height and stem diameter was collected every week. Plant fresh and dry weights were measured at the end of the season. Yield components were measured as, total number of fruits per plant, single fruit weight, fruit diameter, fruit water content, fruit color index (CI), and total yield per plant. CI was measured following [25]. Most of the yield components data were collected at the final harvest.

III. STATISTICAL ANALYSIS

The experiment had a randomized completely block design with one factor and three treatments, each treatment had three replicates for destructive sampling during the experiment. Data set of each variable was subjected to analysis using the statistical package of MSTATC [26]. When F values were significant, means were compared using one-way analyses of variance (ANOVA) followed by LSD test, at $P \leq 0.05$.

IV. RESULTS AND DISCUSSION

I Effect on Soil Properties

Before and after the application of treatments, the soil was analyzed for the physical and chemical parameters such as pH, EC, water content, soil texture and organic matter. These were determined for all the treatments. Results of these parameters are presented in (Table 2). It has been observed that biochar gave the positive response toward these soil parameters. Biochar pH, EC, water content and organic matter

has been increased in all treated plants as compared to control soil.

Soil bulk density (BD) decreased significantly as the biochar quantity went up in each during the growing period. The biggest reduction was presented in treatment 2, with the most reduction of 1.09 g cm^{-3} in the BD, followed by treatments 1, compared to the least in control treatment (CK). These results showed that biochar application indeed made lower soil BD during the growing period. This due to porosity of biochar is very high and when it used in soil it significantly decrease bulk density by increasing the pore volume [22]. Moreover, decrease in soil bulk density following the application of biochar can positively influence root development and growth [27, 28].

The change of soil field capacity (FC), permanent wilting point (PWP) and available water content (AWC) in the pots during the experiment under biochar and without biochar treatments are shown in Table 2 and Fig. 1. It was found that biochar treatments had comparatively higher soil FC and AWC with respect to non-biochar treatment. Biochar treatment T2 showed the highest values of FC and AWC followed by T1 and CK, respectively (Table 2 and Fig. 1). Meanwhile, the PWP value decreased significantly under biochar addition. This due to application of biochar increase the proportion of the soil pore size, and thus enhance soil moisture content and other soil hydrological properties. Our result also agrees with Novak (2009) [29], who stated that additions of biochar to soils can improve soil water storage capability.

The application of biochar did not have any effect on electrical conductivity (EC) and pH of the soil. Meanwhile, the addition of biochar increased soil organic matter, the highest values (0.61 and 0.33 g kg^{-1}) observed at T2 and T1 treatment, respectively (Table 2).

Table 2. Bulk density (BD), field capacity (FC), permanent wilting point (PWP), and available water content (AWC) as affected by different biochar amendments at the end of growing season

Parameters	CK	T1	T2
Bulk density (g cm^3)	01.23 ^a	01.17 ^b	01.09 ^c
Field capacity (%)	31.70 ^c	33.15 ^b	34.81 ^a
Permanent wilting point (%)	13.20 ^a	12.10 ^b	11.63 ^c
Electrical conductivity (dS m^{-1})	1.50 ^a	1.52 ^a	1.52 ^a
pH	8.0 ^a	8.3 ^a	8.2 ^a
Organic matter (g kg^{-1})	2.80 ^c	3.02 ^b	3.25 ^a

Note: Means within rows of each parameter followed by different letters are statistically different at $p < 0.05$ (LSD test).

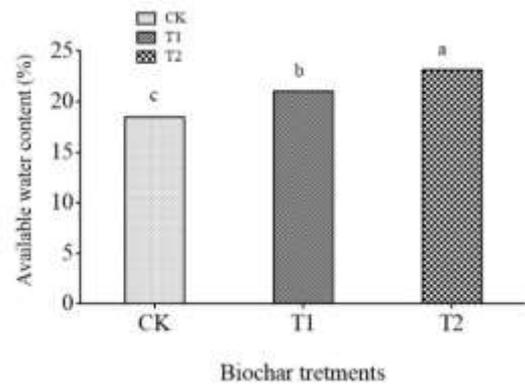


Figure 1. Available water content under different biochar amendments

II Effect on Growth Parameters

The tallest and biggest stem plant were observed in the tomato grown under T2 and T1 conditions. On the other hand, the growth of tomato plants under no biochar amendment (CK) was limited as indicated by shorter and smallest stem plants.

Table 3 shows the effect of biochar on tomato growth parameters. The statistical analysis showed that biochar additions significantly improved growth parameters. Plant height is an important index to reflect tomato yield. During the whole growth stage, plant height per plant displayed obvious differences in all biochar treatments (Table 3). Plant height in treatments 1 and 2 were largest at 25.94 and 23.81 cm, which significant higher than that in control treatment CK, at establishment and growth stage. In flowering growing period, plant height in treatment 2 was biggest at 50.16 cm, followed by treatments 1 and CK. When it come into fruit setting stage, treatment 2 also received the highest value at 73.36 cm, which was significantly higher than the control treatment. At the last growing stage, the treatment 2 and 1 still sustained had the highest plant height.

Stem diameter increased quickly as the biochar quantity went up in each growing period. The biggest increments in each stage was presented in treatment 2, with the most increments of 12.93 mm in stem diameter, followed by treatments 1, compared to the least in control treatment CK at 12.16 mm. These result showed that biochar indeed made higher growth of tomato plant in all growing stages.

Table 4 shows the effects of different biochar application rates on plant fresh and dry weights, at the end of maturity stage. Biochar significantly improved the plant fresh and dry weights. Fresh and dry weights of the whole tomato plant were highest for treatment 2 (126.33 and 61.45 g per plant, respectively) and 100 and 52.87 g, respectively of treatment 1 took the second place. Control treatment ranked last at 85.7 and 41.36 g, respectively. The improvements of tomato growth parameters under biochar application could attributed to the improvements in BD, soil water content and soil organic matter. Our results were in agreement with the result obtained by Hansen (2016) [14], who stated that biochar addition enhanced plant growth.

Table 3. Growth parameters of tomato in the four growth stages under different biochar amendments

Parameters	Treatments	Tomato Growth Stages			
		Establishment and growth	Flowering	Fruit setting	Fruit Ripening
Stem diameter (mm)	CK	6.40 ^b	8.35 ^c	10.68 ^c	12.16 ^b
	T1	7.21 ^a	8.96 ^b	11.39 ^b	12.89 ^a
	T2	7.30 ^a	9.73 ^a	11.98 ^a	12.93 ^a
Plant height (cm)	CK	20.63 ^c	39.22 ^c	58.27 ^c	80.20 ^c
	T1	23.81 ^b	44.50 ^b	65.42 ^b	89.17 ^b
	T2	25.94 ^a	50.16 ^b	73.36 ^a	94.88 ^a

Means within columns of each parameter followed by different letters are statistically different at $p < 0.05$ (LSD test)

III Effect on Yield Component

Effects of different biochar application rates on tomato yield components during the growing period are shown in Table 4 and Fig. 2. Biochar amendments significantly increased all yield components, except fruit diameter and color index were not affected by biochar addition. T2 and T1 treatments recorded highest fruit number per plant, fruit weigh, fruit water content and total yield per plant compare to those under no biochar- control treatments. This attributed to the improvement of soil properties and plant growth parameters under biochar additions. Our result in line with Hammer (2015) [30], who reported that biochar enhanced growth and yield of plant.

Table 4. Growth and yield components of tomato plant under different biochar amendments

Parameters	CK	T1	T2
Fresh plant weight (g)	85.7 ^c	100.0 ^b	126.33 ^a
Dry plant weight (g)	41.36 ^c	52.87 ^b	61.45 ^a
Fruit No. per plant	8.2 ^c	10.5 ^b	12.6 ^a
Fruit diameter	51.23 ^a	51.24 ^a	51.25 ^a
Fruit water content (%)	90.10 ^c	91.89 ^b	93.07 ^a
Fruit color index (CI)	1.25 ^a	1.26 ^a	1.26 ^a

Means within rows of each parameter followed by different letters are statistically different at $p < 0.05$ (LSD test).

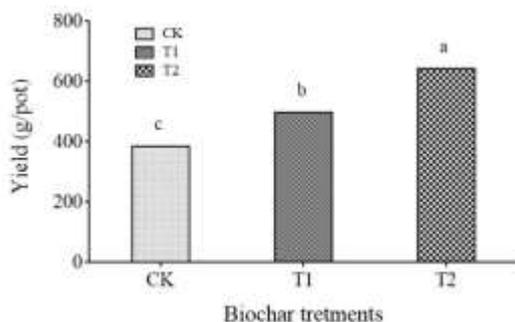


Figure 2. Effect of biochar amendments on tomato yield (g/pot) during tomato growing season.

Similarly, the irrigation water use efficiency (IWUE) was also significantly affected by biochar treatments (Fig. 3). Tomato IWUE increased as the amount of BA rate increased. The highest value obtained at T2 followed by T1 and CK treatment.

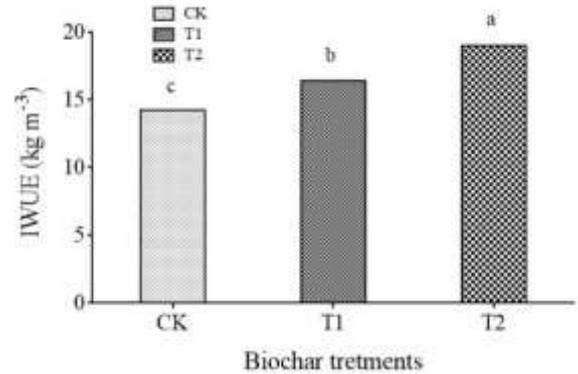


Figure 3. Effect of biochar amendments on Irrigation Water Use Efficiency (IWUE, kg m⁻³) during tomato growing season

CONCLUSION

In this study biochar was used to improve the field capacity, permanent wilting point and available water content of soil in which tomato plant were grown during the season in saline soil condition. The variations were noted and assessment of growth as well as yield parameters was done in experimental conditions. Among all treatments, 4% biochar gave significant results for all parameters as compared to control and other treatments. Soil bulk density, water content and organic matter were significantly increased with increasing application rates of biochar, especially at high application rate. Applying biochar to saline soil had the potential for increasing plant growth, yield components and irrigation water use efficiency of tomato plants. Consequently, under saline soil, biochar might be a promising amendment for improving soil properties and subsequently enhancing plant productivity.

REFERENCES

- [1] Ghassemi F., Jakeman A.J., Nix H.A. Salinisation of Land and Water Resources: Human Causes, Extent Management and Case Studies. UNSW Press, Sydney, Australia and CAB International, Wallingford, UK, 1995
- [2] Szabolcs, I. Salinization of soils and water and its relation to desertification. Desertification Control Bull, 21: 32–37, 1992
- [3] Barrow, C.J. Biochar: potential for countering land degradation and for improving agriculture. Appl Geogr, 34:21–28, 2011
- [4] Mankasingh U., Choi P-C., Ragnarsdottir V. Biochar application in a tropical, agricultural region: A plot scale study in Tamil Nadu, India. Appl Geochem, 26:218–221, 2011
- [5] Reeves, D.W. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Tillage Res, 43: 131–167, 1997
- [6] Powlson D.S., Glendining M.J., Coleman K., Whitmore A.P. Implications for soil properties of removing cereal straw: results from long-term studies. Agron. J, 103: 279-287, 2011

- [7] Enders A., Hanley K., Whitman T., Joseph S., Lehmann J. Characterization of biochars to evaluate recalcitrance and agronomic performance. *Bioresour. Technol*, 114: 644–653, 2012
- [8] Sohi S.P., Krull E., Lopez-Capel E., Bol R. In: Donald, L.S. A Review of Biochar and Its Use and Function in Soil. *Adv. Agron. Academic Press*, pp. 47–82, 2010
- [9] Abiven S., Schmidt M.W.L., Lehmann J. Biochar by design. *Nat. Geosci*, 7: 326–327, 2014
- [10] Jien S.-H., Wang C.-S. Effects of biochar on soil properties and erosion potential in a highly weathered soil. *CATENA*, 110: 225–233, 2013
- [11] Mohan D., Sarswat A., Ok Y.S., Pittman Jr C.U. Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent – a critical review. *Bioresour. Technol*, 160: 191–202, 2014
- [12] Samsuri A.W., Sadegh-Zadeh F., Seh-Bardan B.J. Characterization of biochars produced from oil palm and rice husks and their adsorption capacities for heavy metals. *Int. J. Environ. Sci. Technol*, 11: 967–976, 2014
- [13] Zhang X., Wang H., He L., Lu K., Sarmah A., Li J., Bolan N.S., Pei J., Huang H. Using biochar for remediation of soils contaminated with heavy metals and organic pollutants. *Environ. Sci. Pollut. Res*, 20: 8472–8483, 2013
- [14] Hansen V., Hauggaard-Nielsen H., Petersen C.T., Mikkelsen T.N., Müller-Stöver, D. Effects of gasification biochar on plant-available water capacity and plant growth in two contrasting soil types. *Soil Tillage Res*, 161: 1–9, 2016
- [15] Bruun E.W., Petersen C.T., Hansen E., Holm J.K., Hauggaard-Nielsen H. Biochar amendment to coarse sandy subsoil improves root growth and increases water retention. *Soil Use Manag*, 30: 109–118, 2014
- [16] Uzoma K.C., Inoue M., Andry H., Zahoor A., Nishihara E. Influence of biochar application on sandy soil hydraulic properties and nutrient retention. *J. Food. Agric. Environ*, 9: 1137–1143, 2011
- [17] Abel S., Peters A., Trinks S., Schonsky H., Facklam M., Wessolek G. Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil. *Geoderma*, 202–203: 183–191, 2013
- [18] Madsen, H.B. Distribution of spring barley roots in Danish soils of different texture and under different climatic conditions. *Plant Soil*, 88: 31–43, 1985
- [19] Waters D., van Zwieten L., Singh B.P., Downie A., Cowie A.L., Lehmann J. Biochar in soil for climate change mitigation and adaptation. *Soil Health Clim Change*, 29: 345–368, 2011
- [20] Jeffery S., Verheijen F.G.A., van der Velde M., Bastos A.C. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agric Ecosyst Environ*, 144:175–187, 2011
- [21] Jones D.L., Murphy D.V., Khalid M., Ahmad W., Edwards-Jones G., DeLuca T.H. Short-term biochar-induced increase in soil CO₂ release is both biotically and abiotically mediated. *Soil Biol Bioch*, 43: 1723–1731, 2011
- [22] Lehmann J., Rillig M. C., Thies J., Masiello C. A., Hockaday W. C., Crowley D. Biochar effects on soil biota—a review. *Soil Biol Bioch*, 43: 1812–1836, 2011
- [23] Tan, K.H. Soil sampling, preparation, and analysis. CRC press, 2005
- [24] Nelson DW., Sommers L.E., Sparks D.L., Page A.L., Helmke P.A., Loeppert R.H., Soltanpour P.N., Tabatabai M.A., Johnston C.T., Sumner M.E. Total carbon, organic carbon, and organic matter. *Methods of soil analysis. Part 3-chemical methods*, pp. 961–1010, 1996
- [25] López Camelo A.F., Gómez P.A. Comparison of color indexes for tomato ripening. *Hortic. Brasil*, 22: 534–537, 2004
- [26] Fischer, S.D. MSTAT-C statistical package. Michigan State University, USA, 1990
- [27] Atkinson C. J., Fitzgerald J. D., Hipps N. A. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant and Soil*, 337: 1–18, 2010
- [28] Laird D. A., Fleming P., Davis D.D., Horton R., Wang B., Karlen D.L. (). Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma*, 158: 443–449, 2010
- [29] Novak JM., Lima I., Xing B., Gaskin J.W., Steiner C., Das K.C., Ahmedna M., Rehrh D., Watts DW., Busscher W.J., Schomberg H. Characterization of designer biochar produced at different temperatures and their effects on a loamy sand. *Annals Environ Sci*, 2:195–206, 2009
- [30] Hammer E.C., Forstreuter M., Rillig M.C., Kohler J. Biochar increases arbuscular mycorrhizal plant growth enhancement and ameliorates salinity stress. *Appl Soil Ecol*, 96:114–121, 2015

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