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Effect of Digestate and Biochar Amendments on Photosynthesis Rate, Growth Parameters, Water Use Efficiency and Yield of Chinese Melon (*Cucumis melo L.*) under Saline Irrigation

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Abstract: Despite the recent interest in biochar and digestate as soil amendments for improving soil quality and increasing crop production, there is inadequate knowledge of the effect of the combination of biochar and digestate, particularly under saline irrigation conditions. A pot experiment with Chinese melon was conducted in a greenhouse, biochar (5%) and digestate (500 mL/pot) were used with and without the recommended mineral NPK (Nitrogen, Phosphorus and Potassium) fertilizer dose (120-150-150 Kg ha^{-1}). The plants were irrigated with tap water (SL0) and 2 dS/m (SL1) NaCl solution. The growth, photosynthesis rate, water use efficiency (WUE) and yield of Chinese melon were affected positively when biochar was combined with digestate amendment, particularly under saline irrigation water with and without mineral NPK fertilizer. The maximum yield under normal water was obtained by digestate (SL0: 218.87 t ha^{-1}) and biochar amendment combined with digestate (SL1: 118.8 t ha^{-1}) under saline water. The maximum WUE values were noticed with the biochar and digestate combination under all water treatments (SL0: 32.2 t ha^{-1} mm^{-1} and SL1: 19.6 t ha^{-1} mm^{-1}). It was concluded that digestate alone was more effective than the use of biochar, particularly with normal water. The combination of biochar with digestate had a significant effect on the Chinese melon growth, photosynthesis rate, water use efficiency and yield under saline irrigation, and it can be used as an alternative fertilizer for mineral NPK fertilizer.

Keywords: biochar; digestate; water use efficiency; photosynthesis rate

1. Introduction

Organic farming has become an essential priority area worldwide in view of the growing demand for healthy and safe food, long-term sustainability and concerns regarding the environmental pollution related to the indistinctive utilization of chemical fertilizers, [1]. Organic materials are very important soil amendments that sustain the productivity of soils in tropical and subtropical areas where there is low soil organic carbon (SOC) content and lower input of organic materials [2]. Using organic waste including manure, sewage sludge, and municipal compost in soil is an ideal way to maintain soil organic matter, improve soil quality and provide nutrients essential to plants [3]. Biogas production from organic matter has expanded recently, and therefore the application of digestates—byproducts of anaerobic digestion—to soil as bio-fertilizers has become more common [4]. In a number of incubation and pot experiments the digested slurry enhanced the plant-available N contents in the soil, the plants'

N uptake, as well as crop yields compared with undigested slurry [5]. Digestate is regarded as a liquid from the anaerobic breaking down of animal and plant waste [6]. It consists of significant amounts of mineral elements (nitrogen, phosphorus, potassium) [7]. Furthermore, it includes other macro- and micro-elements essential for plant growth. However, the organic fractions of digestate can play a role in soil organic matter (SOM) turnover, affecting the soil biological, chemical and physical characteristics as a soil amendment [8]. Biochar is a carbonaceous material that may provide the key benefits of increased SOC in the long term. Biochar is generally a low density, porous substance that can improve water and nutrient retention and provide an environment for microorganisms in the soil; overall, improved soil quality is remarkably dependent on the biomass feedstock and the temperature of production, as well as some aspects of the soil being treated [9]. Using biochar and effluent can increase the availability of soil nutrients, water and enhance the root growth environment [10]. Biochar can behave as a sorbent material when used along with liquid digestate and might enhance nutrient balancing in the soil by preventing nutrient runoff to streams and waterways through the soil, therefore increasing plant productivity [11]. However, very limited information is available regarding the application of these soil amendments simultaneously and their effects on soil and crop growth. The purpose of this study is to investigate the effect of biochar and digestate application on the photosynthesis rate, growth parameters, water use efficiency (WUE) and yield of Chinese melon (*Cucumis melo L.*) under saline irrigation.

2. Materials and Methods

2.1. Experimental Design

The experiment was performed in a glasshouse at the Water-Saving Park of Hohai University Jiangning Campus located at latitude 31°57′ N and longitude 118°50′ E, at 144 m above sea level in Nanjing, Jiangsu Province, China. The Northeast Dandong melon seeds provided by the Flower Goddess Company, Suqian -Jiangsu were transplanted into plastic pots (one plant per pot) on 4 May 2017; pot size and shape are provided in Figure 1; the space between each pot was 0.5 m. The soil at the experimental site is clay loam. Table 1 shows the chemical and physical properties of the soil before planting. The experiment was comprised of fourteen treatments as shown in Table 2. The experiment was built with a completely randomized design.

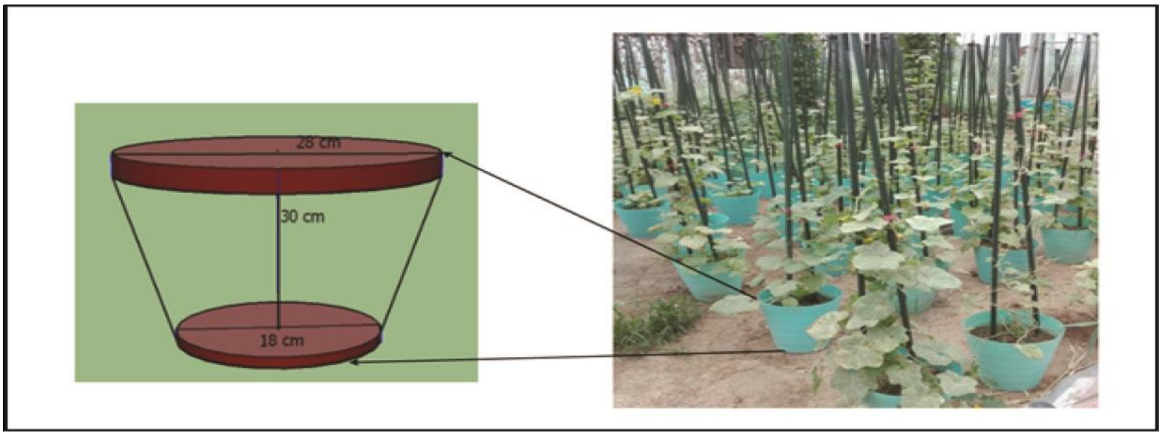

Figure 1. Experimental pot shape and size.

Table 1. The chemical and physical properties of the soil at the experimental site.

Parameter	Soil
EC (1:5) dS m^{-1}	1.06
pH (1:5)	7.7
Sand %	33
Silt %	39
Clay %	28
OC %	0.99
$CaCO_3$ %	1.9
CEC cmol (+) kg^{-1}	36

Table 2. Experimental treatment design.

Treatments	Description
CK SL0	Control with normal water and without inorganic fertilizer (NPK)
CK SL0 + NPK	Control with normal water and with inorganic fertilizer (NPK)
CK SL1	Control with saline water and without inorganic fertilizer (NPK)
CK SL1 + NPK	Control with saline water and with inorganic fertilizer (NPK)
BC + NPK SL0	Biochar with normal water and with inorganic fertilizer (NPK)
BC + NPK SL1	Biochar with saline water and with inorganic fertilizer (NPK)
Di SL0	Digestate with normal water and without inorganic fertilizer (NPK)
Di + NPK SL0	Digestate with normal water and with inorganic fertilizer (NPK)
Di SL1	Digestate with saline water and without inorganic fertilizer (NPK)
Di + NPK SL1	Digestate with saline water and with inorganic fertilizer (NPK)
BC + Di SL0	Biochar + Digestate with normal water and without inorganic fertilizer (NPK)
BC + Di + NPK SL0	Biochar + Digestate with normal water and with inorganic fertilizer (NPK)
BC + Di SL1	Biochar + Digestate with saline water and without inorganic fertilizer (NPK)
BC + Di + NPK SL1	Biochar + Digestate with saline water and with inorganic fertilizer (NPK)

* NPK recommended: 120-150-150 Kg ha^{-1} according to [12,13]. Saline water: 2 dS/m using NaCl. Biochar: 5% (500 g/10 kg of soil). Digestate: 500 mL/pot (equivalent to recommended inorganic NPK).

2.2. Digestate and Biochar Used

2.2.1. Digestate

Digestate (cow and rabbit manure) was acquired from the Farmhouse small manor company, Jining, Shandong. Two digestate doses were used: (1) 12 days after transplanting; and (2) one month after the first dose. The analysis of the digestate is shown in Table 3.

Table 3. Digestate properties.

Parameter	Digestate
EC dS m^{-1}	1.5
pH	7.0–7.5
N g L^{-1}	2.6
P g L^{-1}	1.6
K g L^{-1}	5.1
Organic matter g L^{-1}	>7
Amino acids %	>15
Protein %	>2.5

2.2.2. Biochar

Pinewood biochar from Shandong Tairan Biological Engineering Co., Ltd., Dongying, China was used in this experiment. Table 4 shows the properties of biochar used.

Table 4. Biochar properties.

Parameter	Biochar
EC dS m^{-1}	2.5
pH	6.5
N %	1.4
P_2O_5 %	2.1
K_2O %	1.7
Organic matter %	24

2.3. Photosynthesis, Growth Parameters, Yield and Water Use Efficiency

The Photosynthesis rate was measured using a portable photosynthesis system (TPS-2, PP Systems, Cambridge, UK). The plant height was measured from the stem base to the top further, plant leaves, stem diameter and plant yield were evaluated according to [14]. Water use efficiency was measured from the yield and accumulated water determined according to the following equation, according to [15].

$$\text{Water use efficiency} = \frac{\text{Crop yield (ton)}}{\text{Total water used (gallon)}} \quad (1)$$

2.4. Statistical Analysis

The acquired results were subjected to analysis of variance (one-way ANOVA) with a Tukey's test ($p < 0.05$) according [16], using the MaxStat 3.06 statistical package and GraphPad Prism 6.

3. Results

3.1. Vegetative Growth Stage

3.1.1. Photosynthesis Rate

The photosynthesis rate is significantly affected by the addition of soil amendments (Figure 2). The greatest photosynthesis activity was found in plants treated with BC (Biochar) + Di (Digestate) + NPK (Mineral fertilizer) SL0 (Normal water) (16.3 μmol m^2 s^{-1}) accompanied by BC + Di + NPK SL1 (12.67 μmol m^2 s^{-1}) and Di + NPK SL1 (11.7 μmol m^2 s^{-1}), while minimum activity was observed in CK (Control) SL1 (6.47 μmol m^2 s^{-1}) treated plants flowed by BC + NPK SL1 (11.93 μmol m^2 s^{-1}) as compared with other treatments. Moreover, Di SL0 (12.83 μmol m^2 s^{-1}) did not show a significant difference in comparison with Di + NPK SL0 (13.09 μmol m^2 s^{-1}).

3.1.2. Growth Responses

The plant height of the Chinese melon increased with application of digestate and biochar (Table 5). Maximum plant height (20 cm) was observed with Di + NPK SL0 flowed by Di + NPK SL1 (14.96 cm), Di SL0 (14.83 cm), BC + Di + NPK SL0 (14.2 cm) and BC + Di SL0 (13.20 cm) in comparison with control. This increase in plant height was 62.5% (Di + NPK SL0), 49% (Di SL0) and 43% (BC + Di SL0) when compared to control (CK SL0 + NPK). Moreover, under saline irrigation treatment the plant height increased with soil amendments and inorganic fertilizer (NPK), simultaneously the BC + Di SL1 reflected a good value (11.53 cm) as compared to Di SL1 (9.00) and CKSL1 (5.33 cm). The plant height significantly decreased in control under saline water treatment (CKSL1) compared to other treatments (Figure 3).

The number of Chinese melon leaves increased with the application of digestate and biochar (Table 5). Maximum plant leaves was observed with BC + Di SL0 (12.67) and Di + NPK SL0 (12.67) flowed by BC + Di + NPK SL0 (12.33) and Di SL0 (12.00) compared to control. Without the use of NPK fertilizer the BC + Di SL1 recorded the maximum values (10.33) for the number of leaves under saline irrigation.

The largest stem diameter was observed with Di SL0 (5.33) and Di + NPK SL0 (4.67 mm), as compared with control, CKSL0 (2.00) and CKSL1 (2.00 mm), as shown in Table 5.

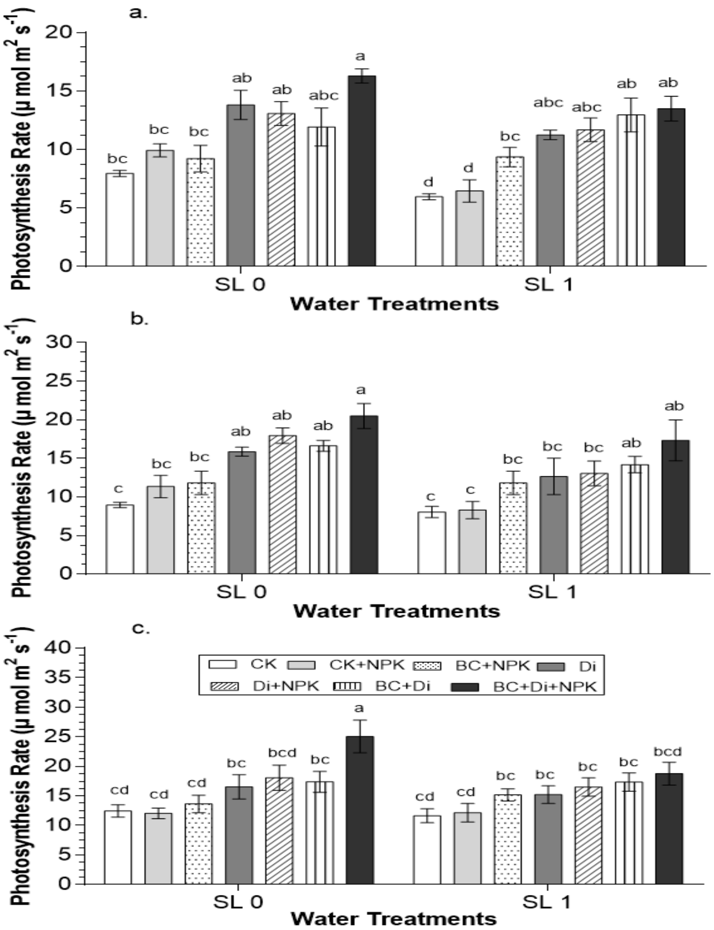

Figure 2. Effect of biochar and digestate treatments on Chinese melon photosynthesis rate (**a**) Vegetative growth; (**b**) Flowering stage and (**c**) Fruit stage under normal water (SL0) and saline water (SL1) treatments.

Table 5. Mean (± Standard deviation) growth parameters of melon plants at the vegetative growth stage.

Treatments	Plant Height (cm)	Number of Leaves	Stem Diameter (mm)
CK SL0	6.10 ^{d,e} ± 0.36	4.33 ^{b,c} ± 0.58	2.00 ^{a,b} ± 0.00
CK SL0 + NPK	7.50 ^{d,e} ± 0.50	5.33 ^{b,c} ± 0.58	3.33 ^{a,b} ± 0.58
CK SL1	5.33 ^{d,e} ± 0.42	5.00 ^{b,c} ± 0.00	2.00 ^{a,b} ± 0.00
CK SL1 + NPK	6.17 ^{d,e} ± 0.29	4.67 ^{b,c} ± 0.58	2.67 ^{a,b} ± 0.58
BC + NPK SL0	7.53 ^{d,e} ± 0.50	4.00 ^{b,c} ± 0.00	3.00 ^{a,b} ± 0.00
BC + NPK SL1	7.43 ^{d,e} ± 0.38	4.00 ^{b,c} ± 0.00	3.00 ^{a,b} ± 0.00
Di SL0	14.83 ^{a,b} ± 0.76	12.00 ^{a} ± 1.00	5.33 ^{a} ± 0.58
Di + NPK SL0	20.00 ^{a} ± 1.00	12.67 ^{a} ± 0.58	4.67 ^{a} ± 0.58
Di SL1	9.00 ^{d,e} ± 0.00	9.07 ^{a,b} ± 1.00	3.67 ^{a,b} ± 0.58
Di + NPK SL1	14.97 ^{a,b} ± 1.27	11.67 ^{a} ± 0.58	4.00 ^{a,b} ± 0.00
BC + Di SL0	13.20 ^{a,b,c,d} ± 1.31	12.67 ^{a} ± 1.16	3.33 ^{a,b} ± 0.58
BC + Di + NPK SL0	14.20 ^{a,b,c} ± 1.48	12.33 ^{a} ± 0.58	4.00 ^{a,b} ± 0.00
BC + Di SL1	11.53 ^{b,c,d,e} ± 1.57	10.33 ^{a} ± 0.58	3.00 ^{a,b} ± 0.00
BC + Di + NPK SL1	11.97 ^{b,c,d,e} ± 0.95	11.00 ^{a} ± 0.00	3.67 ^{a,b} ± 0.58

Means with the same superscripted letters are not significantly different at the 0.05 level.

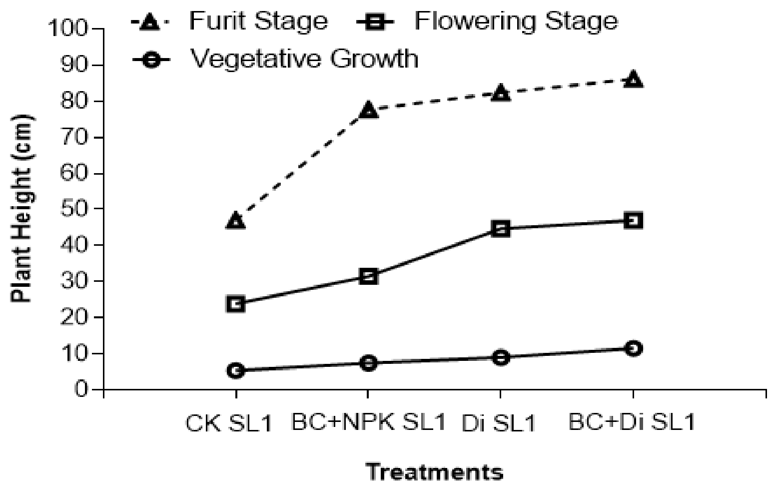

Figure 3. Effect of biochar and digestate treatments on Chinese melon height under saline irrigation water (SL1).

3.2. Flowering Stage

3.2.1. Photosynthesis Rate

The photosynthesis rate at this stage was significantly affected by the use of biochar and digestate (Figure 2), like the previous stage. BC + Di + NPK SL0 recorded the maximum photosynthesis activity flowed with Di + NPK SL0 and BC + Di + NPK SL1.

3.2.2. Growth Responses

The plant height of the Chinese melon increased with the application of digestate and biochar (Table 6). Di SL0 (64 cm), Di + NPK SL0 (59.67 cm) and BC + Di SL0 (56.33 cm) registered the longest plant height compared to control. The plant height increased by about 49% (Di SL0), 46% (Di + NPK SL0) and 42% (BC + Di SL0) compared with control (CK SL0 + NPK). Furthermore, under saline water treatment the soil amendments clearly increased plant height when compared to control, as well as the highest value without the use of NPK fertilizer observed when the biochar combined with the digestate (BC + Di SL1 (47 cm)), as shown in Figure 3.

The application of biochar and digestate significantly increased the number of plant leaves (Table 6). The maximum plant leaf number was noticed with Di + NPK SL0 (43.67) accompanied by Di SL0 (32) and BC + Di + NPK SL0 (30) compared with control. In comparison, under saline irrigation the BC + Di SL1 without NPK registered the maximum values (29.33) of leaves.

The stem diameter at this stage did not show any significant differences between treatments, as shown in Table 6.

Table 6. Mean (± Standard deviation) growth parameters of melon plants at the flowering stage.

Treatments	Plant Height (cm)	Number of Leaves	Stem Diameter (mm)
CK SL0	26.00 ^{c,d} ± 2.00	11.67 ^{d} ± 0.58	4.00 ^{a} ± 0.00
CK SL0 + NPK	32.50 ^{b,c,d} ± 1.23	14.33 ^{d} ± 2.52	4.67 ^{a} ± 0.58
CK SL1	23.83 ^{c,d} ± 0.76	10.67 ^{d} ± 2.08	4.00 ^{a} ± 0.00
CK SL1 + NPK	25.67 ^{c,d} ± 0.58	11.67 ^{d} ± 1.51	4.33 ^{a} ± 0.58
BC + NPK SL0	31.50 ^{b,c,d} ± 1.32	16.00 ^{c,d} ± 2.00	3.66 ^{a} ± 0.58
BC + NPK SL1	31.50 ^{b,c,d} ± 0.95	15.00 ^{c,d} ± 1.00	3.33 ^{a} ± 0.58
Di SL0	64.00 ^{a} ± 1.16	32.00 ^{a,b} ± 1.73	4.67 ^{a} ± 1.16
Di + NPK SL0	59.67 ^{a} ± 0.58	43.67 ^{a} ± 2.51	4.33 ^{a} ± 0.58
Di SL1	44.67 ^{a,b,c} ± 2.00	24.00 ^{a,b,c} ± 2.00	4.00 ^{a} ± 1.00
Di + NPK SL1	57.67 ^{a} ± 3.2	29.67 ^{a,b} ± 1.12	4.33 ^{a} ± 0.58

Table 6. *Cont.*

Treatments	Plant Height (cm)	Number of Leaves	Stem Diameter (mm)
BC + Di SL0	56.33 ^{a} ± 1.53	30.00 ^{a,b} ± 1.00	4.00 ^{a} ± 0.00
BC + Di + NPK SL0	57.00 ^{a} ± 2.65	30.00 ^{a,b} ± 3.51	4.00 ^{a} ± 0.00
BC + Di SL1	47.00 ^{a,b} ± 1.53	29.33 ^{a,b} ± 2.15	3.00 ^{a} ± 0.00
BC + Di + NPK SL1	47.33 ^{a,b} ± 2.08	24.00 ^{a,b,c} ± 2.00	4.00 ^{a} ± 0.00

Means with the same superscripted letters are not significantly different at the 0.05 level.

3.3. *Fruit Stage*

3.3.1. Photosynthesis Rate

As in the previous stage, the photosynthesis rate at this stage was significantly affected by adding biochar and digestate (Figure 2). The maximum photosynthesis activity was observed with BC + Di + NPK SL0 accompanied by Di + NPK SL0 and BC + Di + NPK SL1.

3.3.2. Growth Responses

The variations in Chinese melon growth under different water salinities (SL0 and SL1), biochar and digestate treatments are shown in Table 7. Saline water treatment significantly decreased the growth and yield parameters (height, number of leaves, stem diameter and fruits). Biochar and digestate application had a positive effect on all observed parameters at both salinity levels (SL0 and SL1) compared to the respective unamended control. The longest plant height was observed with Di + NPK SL0 (161 cm) and Di SL0 (111.67 cm), accompanied by BC + Di + NPK S0 (104.67 cm) and BC + NPK SL0 (102 cm) compared with control. Furthermore, under saline water treatment, the soil amendments clearly increased plant height compared to control, and the highest value was observed when biochar was combined with digestate (BC + Di SL1 (86.1 cm)) without using NPK fertilizer, as seen in Figure 3. The maximum number of leaves was noticed with Di + NPK SL0 (156.33) accompanied by Di SL0 (87.67) and BC + Di + NPK SL0 (91) as compared with control. In contrast, under saline irrigation, the BC + Di with and without NPK registered the maximum number of leaves (75.33 and 74.67). The stem diameter did not show any significant differences between treatments, as presented in Table 7.

Table 7. Mean (± Standard deviation) growth parameters of melon plants at the fruit stage.

Treatments	Plant Height (cm)	Number of Leaves	Stem Diameter (mm)
CK SL0	54.50 ^{c} ± 5.21	23.67 ^{d,e} ± 1.45	4.67 ^{a} ± 0.00
CK SL0 + NPK	85.67 ^{b,c} ± 4.36	51.67 ^{c,d} ± 3.50	5.00 ^{a} ± 0.00
CK SL1	47.00 ^{d} ± 3.00	19.67 ^{d,e} ± 2.50	5.33 ^{a} ± 0.00
CK SL1 + NPK	75.33 ^{b,c,d} ± 5.52	33.33 ^{d} ± 4.20	5.33 ^{a} ± 0.57
BC + NPK SL0	102.00 ^{b} ± 7.20	49.33 ^{c,d} ± 6.00	5.00 ^{a} ± 0.00
BC + NPK SL1	77.67 ^{b,c,d} ± 2.50	31.00 ^{d} ± 3.61	4.00 ^{a} ± 0.00
Di SL0	111.67 ^{b} ± 7.61	87.67 ^{b,c} ± 2.50	4.33 ^{a} ± 1.15
Di + NPK SL0	161.00 ^{a} ± 3.50	156.33 ^{a} ± 6.42	5.33 ^{a} ± 0.58
Di SL1	80.67 ^{b,c,d} ± 7.25	57.00 ^{c,d} ± 1.71	4.33 ^{a} ± 1.00
Di + NPK SL1	85.50 ^{b,c} ± 3.50	69.67 ^{b,c,d} ± 3.50	5.00 ^{a} ± 0.00
BC + Di SL0	93.67 ^{b,c} ± 4.93	85.33 ^{b,c} ± 4.51	4.00 ^{a} ± 0.00
BC + Di + NPK SL0	104.67 ^{b} ± 6.08	91.00 ^{b,c} ± 2.00	5.67 ^{a} ± 0.00
BC + Di SL1	88.30 ^{b,c} ± 3.10	74.67 ^{b,c,d} ± 4.16	4.00 ^{a} ± 0.00
BC + Di + NPK SL1	88.57 ^{b,c} ± 1.27	75.33 ^{b,c,d} ± 4.51	4.00 ^{a} ± 0.00

Means with the same superscripted letters are not significantly different at the 0.05 level.

3.4. Water Use Efficiency (WUE) and Yield

The present study shows the effects of biochar and digestate on the WUE and yield of Chinese melon. Our results demonstrated that biochar and digestate markedly increased the WUE under normal and saline water with and without the use of mineral fertilizer (NPK), as presented in Figure 4. The results indicated that the highest WUE values were obtained by the BC + Di under both SL0 (32.2 t ha^{-1} mm^{-1}) and SL1 (19.6 t ha^{-1} mm^{-1}) water treatments, while the yield of Di (218.87 t ha^{-1}) and BC + Di (210.69 t ha^{-1}) was the best under SL0 in comparison with other treatments. Further, with water SL1 the BC+Di (112.7 t ha^{-1}) and BC+Di with NPK (118.8 t ha^{-1}) recorded the maximum yield values, as shown in Figure 5.

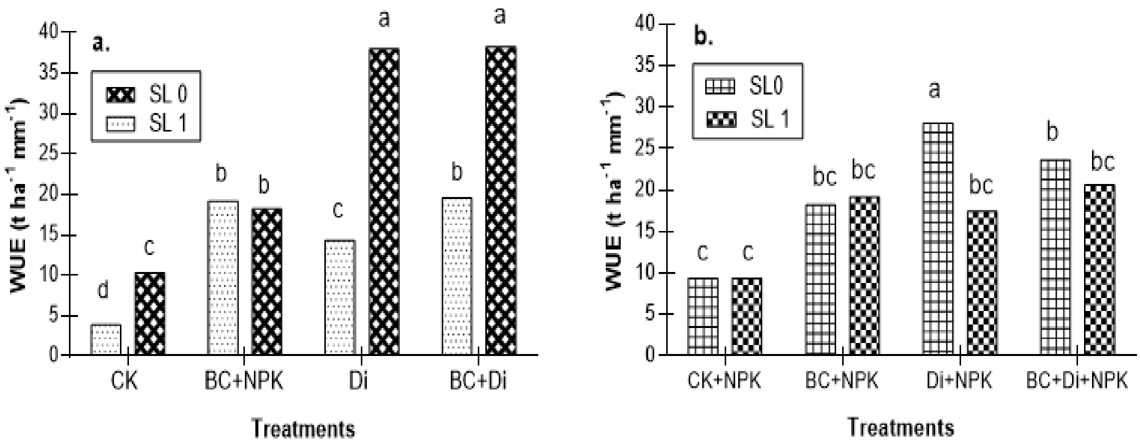

Figure 4. Effect of biochar and digestate treatments on water use efficiency (WUE) ((**a**) Without NPK and (**b**) With NPK fertilizer) under different saline water treatments (SL0 and SL1).

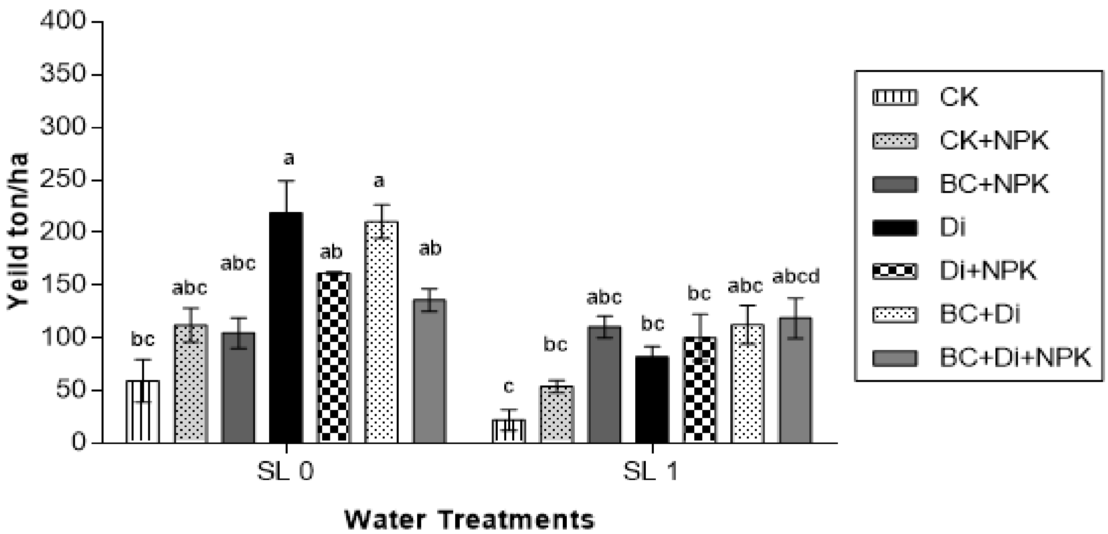

Figure 5. Effect of biochar and digestate treatments on yield of Chinese melon under different saline water treatments (SL0 and SL1).

4. Discussion

Our findings indicated that photosynthesis increased with the application of biochar and digestate under normal and saline irrigation conditions. The maximum photosynthesis activity was observed when biochar was combined with digestate in the presence of NPK fertilizer at all plant growth stages. Biochar with digestate can act as alternative fertilizer for mineral NPK fertilizer, regarding this, our results demonstrated that the combination of biochar with digestate increased the photosynthesis rate under normal irrigation water by about 13% (vegetative growth), 32% (flowering stage) and 31% (fruit stage) when compared to control that received NPK fertilizer, while the rate was 50%, 42% and 30% for the vegetative growth, flowering stage and fruit stage, respectively, under saline irrigation water. In their report, [17] indicated similar findings when biochar was applied to melon plants and they attributed the increase in the photosynthesis rate to the role of biochar in reducing the soil respiration, soluble salt content in the soil, and greenhouse gas CO_2 emissions and therefore improving the net photosynthetic rate. Due to significant amounts of mineral elements (macro- and microelements) and organic fractions, digestate can enhance nutrients availability and thus plant growth [8]. Our findings are in agreement with the outcomes of [10], which explained that the combination of biochar with digestate increased the soil nutrient availability, water and thus physiological parameters.

The results from the present study show that the application of digestate with mineral fertilizer significantly ($p < 0.05$) increased plant height, particularly at the vegetative growth (20 cm) and fruit stages (161 cm) compared to other treatments, while at the flowering stage there was no significance difference between digestate treatments and biochar with digestate. This increase in plant height is due to the high nutrient concentrations and organic matter of the digestate (Table 7), in addition to the available nutrients in mineral fertilizer [18,19]. The number of Chinese melon leaves significantly increased ($p < 0.05$) with the addition of biochar and digestate compared to control. A significant effect of the soil amendments on stem diameter was obtained by digestate treatments under vegetative growth with normal water (Table 5). The combination of biochar and digestate increased the plant height, number of leaves and stem diameter compared with mineral fertilizer. Furthermore, under saline water treatment, the biochar with digestate increased the plant height about 36%, 22% and 54% under vegetative growth compared to biochar, digestate and control, respectively. At the flowering stage, this was 33%, 5% and 49%, and at the fruit stage this was 12%, 9% and 47% compared to biochar, digestate and control, respectively. This could in fact be a result of, firstly, the increased soil moisture availability due to the biochar addition causing a dilution of salt in the soil solution, thus decreasing osmotic stress [20]. Furthermore, an increased soil moisture content due to biochar addition has also been reported by many authors [21,22]. Secondly, biochar contains a high amount of vital plant nutrients (depending upon feedstock and production conditions) (Table 4). According to [23,24], biochar needs to be used along with mineral fertilizer because they observed that biochar application increased nitrogen utilization from the applied fertilizer and thus increased the crop yield. For these reasons, we noticed that biochar application enhanced plant growth more than the control, and became more effective when combined with digestate compared to the use of mineral NPK.

In the present study, the addition of biochar and digestate amendments significantly increased ($p < 0.05$) the melon yield. Digestate combined with biochar was found to be more effective under both irrigation water treatments compared to other treatments that received NPK fertilizer. Generally, the saline irrigation treatment caused a reduction in yield, this reduction has been attributed to reduced water availability, as [25] found in their experiment. The application of biochar with digestate amendment increased the yield and WUE under both irrigation water treatments (SL0 and SL1). The higher WUE of the crop that received organic inputs was positively linked to improved physicochemical properties [26].

5. Conclusions

In our experiment, the digestate exhibited positive effects on the growth, photosynthesis rate, water use efficiency (WUE) and yield of Chinese melon when normal water was used. The combination of biochar with digestate was a very effective fertilization method, particularly under saline irrigation conditions, compared to mineral NPK fertilizer. The maximum yield value under normal water was acquired by digestate (SL0: 218.87 t ha^{-1}) and biochar amendment combined with digestate (SL0: 210.69 t ha^{-1} and SL1: 118.8 t ha^{-1}). The maximum WUE values were observed when using biochar combined with digestate under all water treatments (SL0: 32.2 t ha^{-1} mm^{-1} and SL1: 19.6 t ha^{-1} mm^{-1}). As a conclusion, we found that digestate with biochar was very effective in increasing the growth, WUE and yield of Chinese melon. However, digestate alone was more effective than using biochar, particularly with normal water. The combination of biochar with digestate could not only be an alternative for mineral NPK, but can also be useful under saline irrigation conditions.

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Author Contributions: Author M.M.A. Elbashier designed the experiments and collected data; author S. Xiaohou managed the experimental process, revised and approved the manuscript. A.A.S. Ali and A. Mohmmed contributed analysis tools. This work was carried out in a collaboration between all authors.

Conflicts of Interest: The authors declare no conflict of interest.

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