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Corn Cob-Derived Biochar Improves the Growth of Saline-Irrigated Quinoa in Different Orders of Egyptian Soils

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Abstract: Biochar is one of the important recycling methods in sustainable development, as it ensures the transformation of agricultural wastes into fertilizers and conditioners that improve soil properties and fertility. In the current study, corn cob-derived biochar (CB) was used to reduce the negative effects of saline water on quinoa (*Chenopodium quinoa cv. Utosaya Q37*) grown on Aridisols and Entisols, which are the major soil groups of Egyptian soils. Quinoa plants were cultivated in pot experiment and were irrigated with saline water (EC = 10 dS m^{-1}). The experiment contained three treatments, including control without any treatment, biochar at a rate of 1% (*w/w*) (BC_1), and biochar at a rate of 3% (*w/w*) (BC_3). The findings of the current study showed that BC treatments realized significant effects on soil salinity, pH, soil organic matter (SOM), and plant availability and nutrients' uptake in the two soils types. BC_3 increased the SOM in Entisols and Aridisols by 23 and 44%; moreover, the dry biomass of quinoa plants was ameliorated by 81 and 41%, respectively, compared with the control. Addition of biochar to soil increased the nutrients' use efficiencies by quinoa plants for the two studied Egyptian soils. Biochar addition caused significant increases in the use efficiency of nitrogen (NUF), phosphorus (PUE), and potassium (KUE) by quinoa plants. BC_3 increased NUE, PUE, and KUS by 81, 81, and 80% for Entisols, while these increases were 40, 41, and 42% in the case of Aridisols. Based on the obtained results, the application of corn cob biochar improves the soil quality and alleviates the negative effects of saline irrigation on quinoa plants grown on Aridisols and Entisols Egyptian soils. Biochar can be used as a soil amendment in arid and semi-arid regions to reduce the salinity hazards.

Keywords: soil amendments; saline water; nutrients' availability; Egyptian soils

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1. Introduction

Water scarcity has become a major problem for food security in North Africa and Middle East countries, which cover about 854 million hectares; only 14% of this is suitable for agricultural production [1]. In Egypt, only about 5% of the total land area is suitable for agricultural uses [1]. According to the World Resources Institute, all countries in North Africa and most countries in the Middle East are experiencing water stress, and there are little or no additional resources to supplement existing supplies [1,2]. These limited water and land resources, in addition to rapidly depleting and degrading, require a reassessment of their agricultural development policy [2,3].

Sandy soils (Aridisols) and clay soils (Entisols) as two major soil groups were identified in Egypt [4]. Low soil organic matter (SOM) content for these soils, especially in coarse textured (Aridisols), was reported by Yost and Hartemink [5]. Although the area of Egypt is approximately one million km^2, the area of agricultural land does not exceed 3% of the total area, with a total of about 3.6 million hectares [1]. Most of the newly reclaimed soils of Egypt are mainly sandy and sandy calcareous, which are very poor in organic matter and plant nutrients [6]. Calcareous soils are found in arid and semi-arid conditions and are characterized by high alkalinity and low content of plant nutrients [7]. The lands spread in dry and semi-arid areas are also characterized by a low content of organic matter, as the dry climate leads to the rapid decomposition of organic compounds [8].

Salt-tolerant plants that are able to tolerate high salinity levels have the ability to grow at high salinity with a reasonable growth [9]. Among salt tolerant plants, quinoa (*Chenopodium quinoa*) is native to the Andean region and has attracted a growing global interest thanks to its unique nutritional value [10]. Quinoa plants show tolerance to frost, salinity, and drought and have the ability to grow on most soils [11]. Quinoa has a special importance in human nutrition owing to its high nutritional value, as it contains a large amount of proteins and important amino acids, thus containing a large amount of important nutrients for humans [11]. There are many types of soil in Egypt, as well as in arid and semi-arid regions, which suffer from high salt content and are not suitable for the production of salt-sensitive crops. There are also huge quantities of water resources with a high level of salt and are not used in agricultural production in an optimal manner. Little is known about the response of quinoa plants to organic amendments, e.g., biochar under salinity stress.

Biochar (BC) is a carbon (C)-rich, porous material produced during the process of pyrolysis, which involves thermochemical decomposition of organic matter in an oxygen-limited environment [12]. It represents a carbonaceous material intentionally produced from different biomass, which is widely used as an amendment to improve soil fertility [13]. Application of biochar (BC) to soils has received increasing attention for improving crop productivity and agriculture sustainability [14]. It has been shown to be a promising soil amendment that increases fertility, carbon sequestration, and nutrient retention [15]. The use of corn cob-derived biochar may increase the productivity of quinoa under saline condations; therefore, it can be grown using saline water, which is not suitable for the cultivation of salt-sensitive crops.

Improvement of quinoa growth with biochar additions represents an important step to expand the cultivation of quinoa using limited water [16]. Moreover, biochar can improve the chemical, physical, and biological properties of soil [17] as well as soil quality [18]. In arid and semi-arid regions, calcareous sandy soils suffer from nutrient deficiency, organic matter, and poor structure [19]. It has been demonstrated that biochar can act as a slow-release source of nutrients, and can provide macronutrients and improve soil physicochemical properties such as water holding capacity, pH, and aeration [20]. Therefore, biochar addition to saline soils may be a suitable approach for improving soil quality and enhancing plant growth [21]. Biochar addition to the saline-irrigated plants reduced the accumulation of Na^+ nad Cl^- in the plant tissues; therefore, biochar helps the plant to bypass the effect of salt ions [22,23].

With the constant increasing of the population and scarcity of water, it has become necessary to use saline water in agricultural production. The soils that are spread in dry and semi-arid areas are characterized by their low content of organic matter, and the climatic conditions in these areas encourage the rapid decomposition of organic materials added in the form of compost or manure. We hypothesize that the addition of biochar, which contains more stable and resistant organic materials, will improve soil properties in arid and semi-arid areas. The purpose of this study is to evaluate the effect of corn cob-derived biochar on soil chemical properties of Aridisols and Entisols soils and to investigate the response of quinoa plants to these levels of biochar under saline condition.

2. Material and Methods

2.1. Biochar Production and Characterization

Corn cob biochar was pyrolyzed at 350 °C for 3 h. The prepared biochar was crushed and sieved through a 2 mm sieve. Total organic carbon was determined using the loss-on-ignition method described by [24]. The pH was measured by a digital pH meter in 1:5 (soil/water) suspension, and electrical conductivity (EC) was determined using the salt bridge method in a 1:5 (soil/water) extract [25]. A mixture of H_2SO_4 and H_2O_2 as described by Parkinson and Allen [26] was used to analyze the total N, P, and K content. Chemical properties of the used biochar are listed in Table 1.

Table 1. Main properties of the used biochar.

pH (1:5)	EC (1:5) (dS m^{-1})	O. M (g kg^{-1})	C/N Ratio	Total (g kg^{-1})		
				N	P	K
11.38	5.5	930	26	18	3.2	29

Each value represents a mean of three replicates.

2.2. Pot Experiment

Under saline conditions, the pot experiment was carried out using surface soil samples (0–20) of sandy soil (Aridisols: Typic Torri psamments) and clay loam (Entisols: Typic Torri Fluvents), which were identified by Soil Survey Staff [27] as the two main groups of Egyptian soils. Table 2 shows the climatic conditions of the expermental site. This study aims to investigate the effects of corn cob biochar (BC) on some soil properties and growth of quinoa plants treated with saline water (EC = 10 dS m^{-1}). The basic soil characteristics of the tested soils are shown in Table 3. Four kilograms (from surface soil layer, 0–20) was mixed homogeneously with biochar (BC) and filling in plastic pots. BC rates were 0, 1, and 3% (*w/w*) (control, BC_1, and BC_3, respectively). Each treatment was replicated five times.

Table 2. Basic climatic data of the experimental site during the period of the study (November–February 2020).

Month	T_{max}	T_{min}	Relative Humidity (%)	Solar Radiation (MJ/m^2/Day)	Wind Speed (km h^{-1})	ET_o (mm)
November	27.8	14.2	60	28.0	4.0	2.6
December	23.7	12.3	55	25.0	3.5	2.4
January	18.6	7.2	50	26.0	2.2	2.0
February	21.4	8.9	45	24.0	2.7	1.5

No rainfall was recorded during the experiment period. The data were obtained from the Assiut meteorological station.

Table 3. Some physical and chemical characteristics of the studied soils.

Poperty	Unit	Entisols	Aridisols
Sand	(g/kg)	255	901
Silt	(g/kg)	389	70
Clay	(g/kg)	356	29
Texture	—	Clay loam	Sandy
$CaCO_3$	(g/kg)	22	259
pH (1: 2.5)	—	8.20	7.78
ECe	(dS/m)	0.98	0.33
Organic matter	(g/kg)	12.81	5.69
Available N	(mg/kg)	83	27
Available P	(mg/kg)	9.0	5.4
Available K	(mg/kg)	420	32.0

Seeds of quinoa (*Chenopodium quinoa* cv. Utosaya Q37) were brought from the Desert Research Center, which belongs to the Egyptian Ministry of Agriculture and Land Reclamation, Giza, Egypt. The seeds were genetically identified at the Desert Research Center and are known as Utosaya Q37. Four seeds of quinoa (*Chenopodium quinoa Willd* L.) were sewn in each pot on 1 November 2020, thinned to two plants per pot after full germination. Nitrogen was added with the irrigation water at a level of 0.75 g N/pot as urea (46% N) after 15 and 30 days from sowing, respectively. Tap water was used for irrigation within the first month to ensure the optimum plant growth, then artificial saline water containing a 2:1 molecular weight ratio of NaCl and $CaCl_2$ salts having EC = 10 dS m^{-1} was used for another two months. During the experiment period, the amount of moisture was near the field capacity via daily addition of evaporated water. After 90 days from sowing, plant height and fresh weight per pot were recorded. The harvested plants were washed with distilled water and oven-dried at 70 °C, then the total dry matter weight per pot was estimated. For N, P, and K, nutrient use efficiencies were calculated to evaluate their effects with biochar application according to the following equation:

$$\text{Nutrient use efficiency (g/g nutrient)} = \frac{\text{Dry shoot weight at applied N, P, or K (g/pot)}}{\text{amount of N, P, or K applied with biochar (g/pot)}} \quad (1)$$

2.3. Plant and Soil Analysis

The plants samples were digested with a mixture of H_2SO_4 and H_2O_2, as described by Parkinson and Allen [26]. Total amounts of N, P, and K were analyzed according to the standard methods described by Page et al. [28]. Chlorophyll a (Chl-A), chlorophyll b (Chl-B), total chlorophyll (Chl A+B), and carotenoid contents as photosynthetic pigments were extracted by ethyl alcohol (95%) and then measured by spectrophotometry (Unico 2000UV, Unico photometers & spectrophotometers, Ontario, Canada) at 663, 644, and 452 nm, respectively [29]. At the end of the experiment, soil samples were taken from each pot, air-dried, crushed, passed through a 2 mm sieve, and then analyzed for the physical and chemical properties. Particle size distribution was measured as described by Jackson [30]. The soil pH was determined by a glass electrode [30] and the electrical conductivity (EC) by using an EC meter [31] in a 1:2.5 ratio of a soil to deionized water suspension. The soil organic matter (SOM) was determined by using the Walkley–Black method [30]. Available nitrogen was measured in 2 M potassium chloride extract using micro-kjeldahl method Burt [25]. Available phosphorus was determined by spectrophotometer in 0.5 M sodium bicarbonate solution at pH 8.5 according to Olsen et al. [32]. Ammonium acetate solution was used as an extract to measure available potassium by flame photometry, as described by Jackson [30].

2.4. Statistical Analysis of the Obtained Results

Shapiro–Wilk test was run to check the normality of the obtained data and no changes were needed. One-way analysis of variance (ANOVA) was run to test the significance of differences between the studied treatments, and then the means were compared by Duncan multiple range tests at $p < 0.05$. SPSS 17.0 software package (SPSS, Chicago, IL, USA) was used in the statistical analysis of the data.

3. Results

3.1. Soil Chemical Characteristics

The application of biochar (BC) had significant effects on the soil chemical properties (pH, soil salinity (EC), and soil organic matter (SOM)) of the tested soils, as shown in Table 4. The magnitude effect depends on soil type and BC levels. Our study indicated that biochar (BC) addtion affected the soil pH significantly in the two studied soils. BC had a slight effect on Aridisols pH, while the Entisols soil showed the highest pH increases. In both soil types, the electrical conductivity (EC) was incrementally affected by increasing BC levels. BC had lower effects on Entisols than Aridisols, which had the highest EC values. Addition of BC_1 and BC_3 increased the soil EC by 2.3 and 7.3%, respectively, for Entisols soil, and by 14.8 and 38.3%, respectively, for Aridisols soil, compared with the untreated soil. Soil organic matter (SOM) significantly ($p < 0.05$) increased as a result of BC application in the two studied soil types. SOM increased by 16 and 23%, respectively, as a result of BC_1 and BC_3 treatments for Entisols, and 26 and 44%, respectively, for Aridisols over the control. From previous results, biochar as a soil amendment caused the highest increase in the EC and SOM in Aridisols than in Entisols, while the opposite trend was observed with soil reaction (pH).

Table 4. Effect of biochar application on soil pH, EC, and soil organic matter (SOM).

Treatments	pH (1:2.5)		EC (1:2.5) (dS m^{-1})		SOM (g kg^{-1})	
	Entisols	Aridisols	Entisols	Aridisols	Entisols	Aridisols
Control	7.32 ± 0.9 [b]	7.88 ± 0.2 [b]	3.46 ± 0.8 [b]	2.36 ± 0.7 [b]	12.59 ± 0.43 [b]	6.44 ± 0.58 [b]
BC_1	7.44 ± 0.7 [ab]	8.03 ± 0.1 [ab]	3.54 ± 0.6 [b]	2.71 ± 0.6 [ab]	14.59 ± 0.62 [a]	8.11 ± 0.62 [a]
BC_3	7.61 ± 0.4 [a]	8.17 ± 0.3 [a]	3.71 ± 0.7 [a]	3.26 ± 0.8 [a]	15.53 ± 0.51 [a]	9.29 ± 0.72 [a]
F test	*		*		**	

BC_1 = 1% biochar. BC_3 = 3% biochar. Means denoted by the same letter indicate no significant difference according to Duncan's test at $p < 0.05$. F = the analysis of variance (ANOVA) results between the two soil types, * $p < 0.05$ and ** $p < 0.01$.

3.2. Nutrient Availability and Uptake

In the current study, the available soil nitrogen (N) and potassium (K) were significantly ($p < 0.05$) improved with BC application in each soil type than in the control (Table 5). Addition of BC_1 and BC_3 to Entisols soil increased availability of nitrogen by 25.54 and 37.94%, respectively, and by 70.74 and 12.69 %, respectively, for Aridisols soil compared with the control. The application of biochar at rates of 1 (BC_1) and 3% (BC_3) increased soil potassium availability by about 18.33 and 54.34%, respectively, and by about 13.64 and 86.71%, respectively, over the control. Inversely, a reduction in the availability of phosphorus for each soil type as a result of biochar application was obtained.

Table 5. Effect of biochar application on nutrients' availability and their uptake.

Treatments	Available (mg kg^{-1})					
	N		P		K	
	Entisols	Aridisols	Entisols	Aridisols	Entisols	Aridisols
Control	33.65 ± 1.9 [c]	24.40 ± 1.5 [b]	11.5 ± 0.7 [a]	6.5 ± 0.5 [a]	404 ± 13 [c]	381 ± 12 [c]
BC1	42.25 ± 3.7 [b]	41.65 ± 1.3 [a]	10.6 ± 0.9 [a]	5.5 ± 0.3 [a]	478 ± 15 [b]	433 ± 11 [b]
BC3	46.42 ± 2.5 [a]	27.49 ± 2.3 [b]	9.5 ± 0.8 [a]	4.8 ± 0.2 [a]	623 ± 12 [a]	712 ± 12 [a]
F test	**		**		**	
	Uptake (mg pot^{-1})					
Treatment	N		P		K	
	Entisols	Aridisols	Entisols	Aridisols	Entisols	Aridisols
Control	209 ± 10 [c]	84 ± 7 [c]	10.5 ± 0.9 [c]	3.6 ± 0.3 [c]	45.5 ± 15 [c]	36.3 ± 10 [c]
BC1	235 ± 15 [b]	95 ± 8 [ab]	12.3 ± 0.5 [b]	5.1 ± 0.7 [b]	73.7 ± 9 [b]	42.7 ± 15 [b]
BC3	333 ± 13 [a]	108 ± 12 [a]	15.9 ± 0.4 [a]	6.7 ± 0.3 [a]	105.5 ± 10 [a]	59.0 ± 12 [a]
F test	**		**		**	

BC_1 = 1% biochar. BC_3 = 3% biochar (*w/w*). Means denoted by the same letter indicate no significant difference according to Duncan's test at $p < 0.05$. F = the ANOVA results between the two soil types, ** $p < 0.01$.

Uptake of N, P, and K by quinoa plants was significantly ($p < 0.05$) improved by the biochar additions in the two studied soils types. Application of BC_1 and BC_3 to Entisols soil significantly ($p < 0.05$) increased N uptake by about 12 and 59%, respectively, compared with the control. Meanwhile, on the effect of these biochar levels on Aridisols, N uptake was increased by 13 and 29%, respectively, compared with the control. In addition, the application of BC_1 and BC_3 to Entisols soil increased K uptake by 62 and 132%, respectively, in comparison with the control. In the case of Aridisols soil, BC_1 and BC_3 levels increased K uptake by about 18 and 62%, respectively.

3.3. Plant Growth Parameters and Some Photosynthetic Pigments

The recorded growth parameters of quinoa plants were signifcantly increased by the addition of BC. The height of quinoa plants was significantly ($p < 0.05$) increased owing to the application of BC_1 and BC_3 to Entisols soil, which was increased by 16 and 41%, respectively, compared with the control (Figure 1). Meanwhile, application of BC_1 and BC_3 to Aridisols soil increased the plant height by 30 and 62%, respectively, above the control. The fresh weight of quinoa plants was significantly ($p < 0.05$) increased owing to the application of BC_1 and BC_3 to Entisols soil, which was increased by 36 and 58%, respectively, compared with the control (Figure 1). Meanwhile, application of BC_1 and BC_3 to Aridisols soil increased the fresh weight by 68 and 103%, respectively, above the control. The dry weight of quinoa plants was significantly ($p < 0.05$) increased owing to the application of BC_1 and BC_3 to Entisols soil, which was increased by 25 and 82%, respectively, compared with the control (Figure 1). Meanwhile, application of BC_1 and BC_3 to Aridisols soil increased the dry weight by 15 and 41%, respectively, above the control.

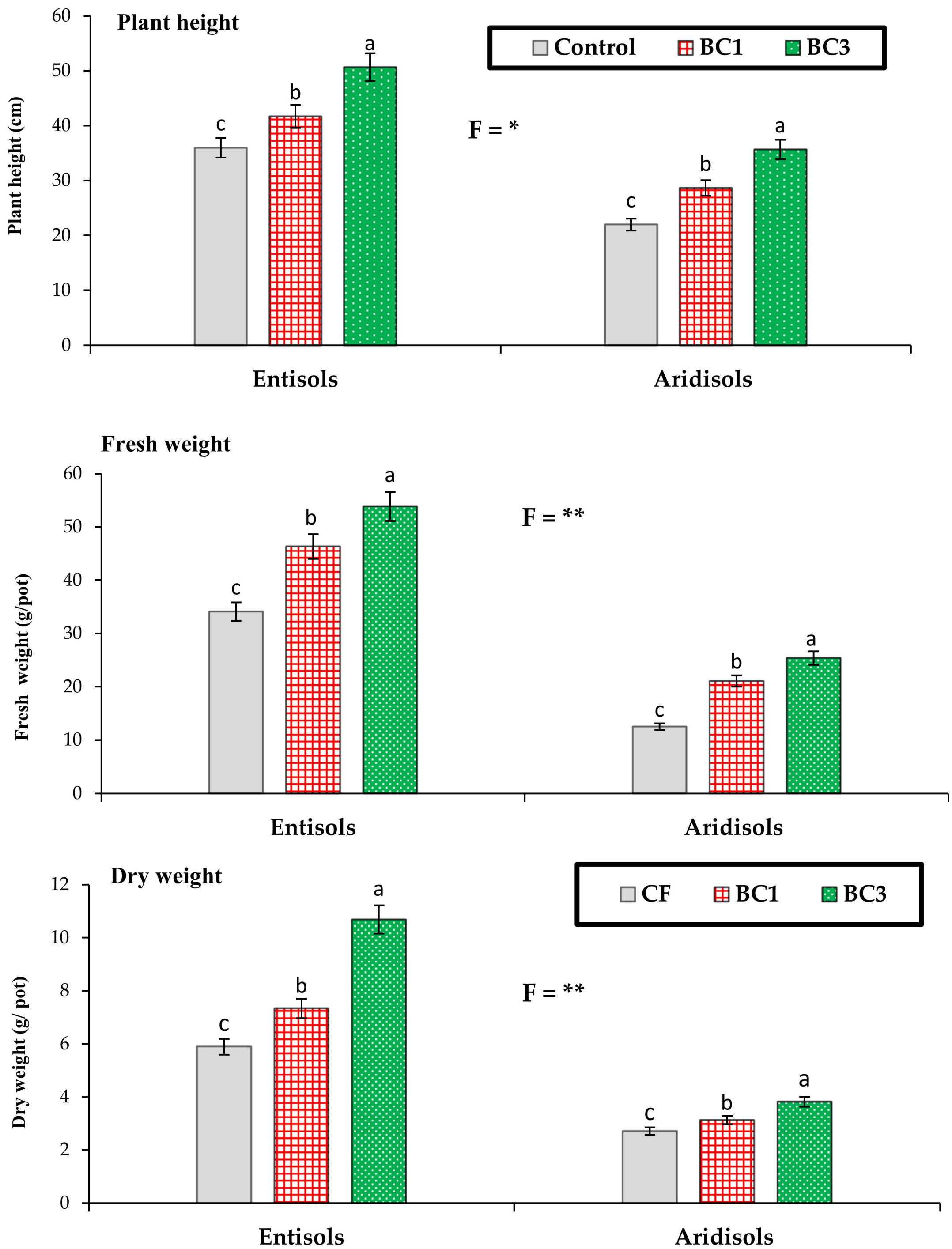

Figure 1. Effect of biochar application on the growth of quinoa plants. BC_1 = 1% biochar. BC3 = 3% biochar (*w/w*). Means denoted by the same letter indicate no significant difference according to Duncan's test at $p < 0.05$. F = the ANOVA results between the two soil types, * $p < 0.05$ and ** $p < 0.01$.

Photosynthetic pigments of quinoa plants in the two soil types were significantly ($p < 0.05$) increased as a result of BC application compared with the control (Figure 2). The application of BC_3 increased chl-A, chl-B, total chl (A+B), and carotenoids by 47, 41, 42, and 56%, respectively, for Entisols soil, and by 77, 62, 67, and 87%, respectively, for Aridisols compared with the control.

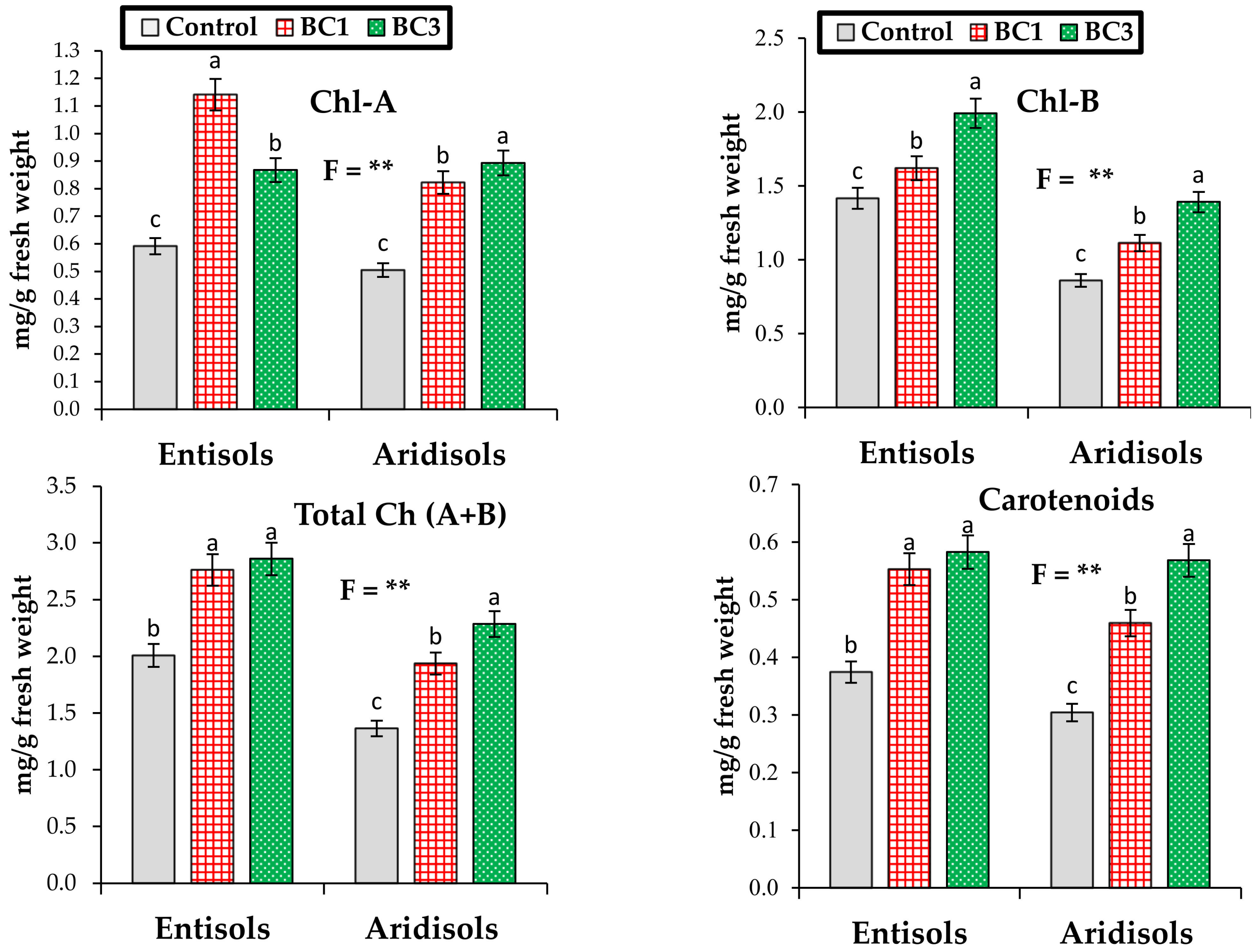

Figure 2. Effect of biochar application on photosynthetic pigments in the shoot tissues of quinoa plants. Chl A= chlorophyll a. Chl B= chlorophyll b. Chl A+B= chlorophyll a and b. BC_1 = 1% biochar. BC_3 =3% biochar (*w/w*). Means denoted by the same letter indicate no significant difference according to Duncan's test at $p < 0.05$. F = the ANOVA results between the two soil types * $p < 0.05$, ** $p < 0.01$.

3.4. Nitrogen, Phosphorus, and Potassium Use Efficiencies

Significant increases were observed in the use efficiencies of nitrogen (NUF), phosphorus (PUE), and potassium (KUE) by quinoa plants with the application of biochar to the Entisols and Aridisols compared with the control (Figure 3). The highest level of biochar (BC_3) increased NUE from 7.86 to 14.25, PUE from 5.90 to 10.69, and KUE from 9.07 to 16.45 g g^{-1} for Entisols. Moreover, it increased NUE from 3.63 to 5.10, PUE from 2.72 to 3.82, and KUE from 4.18 to 5.88 for Aridisols.

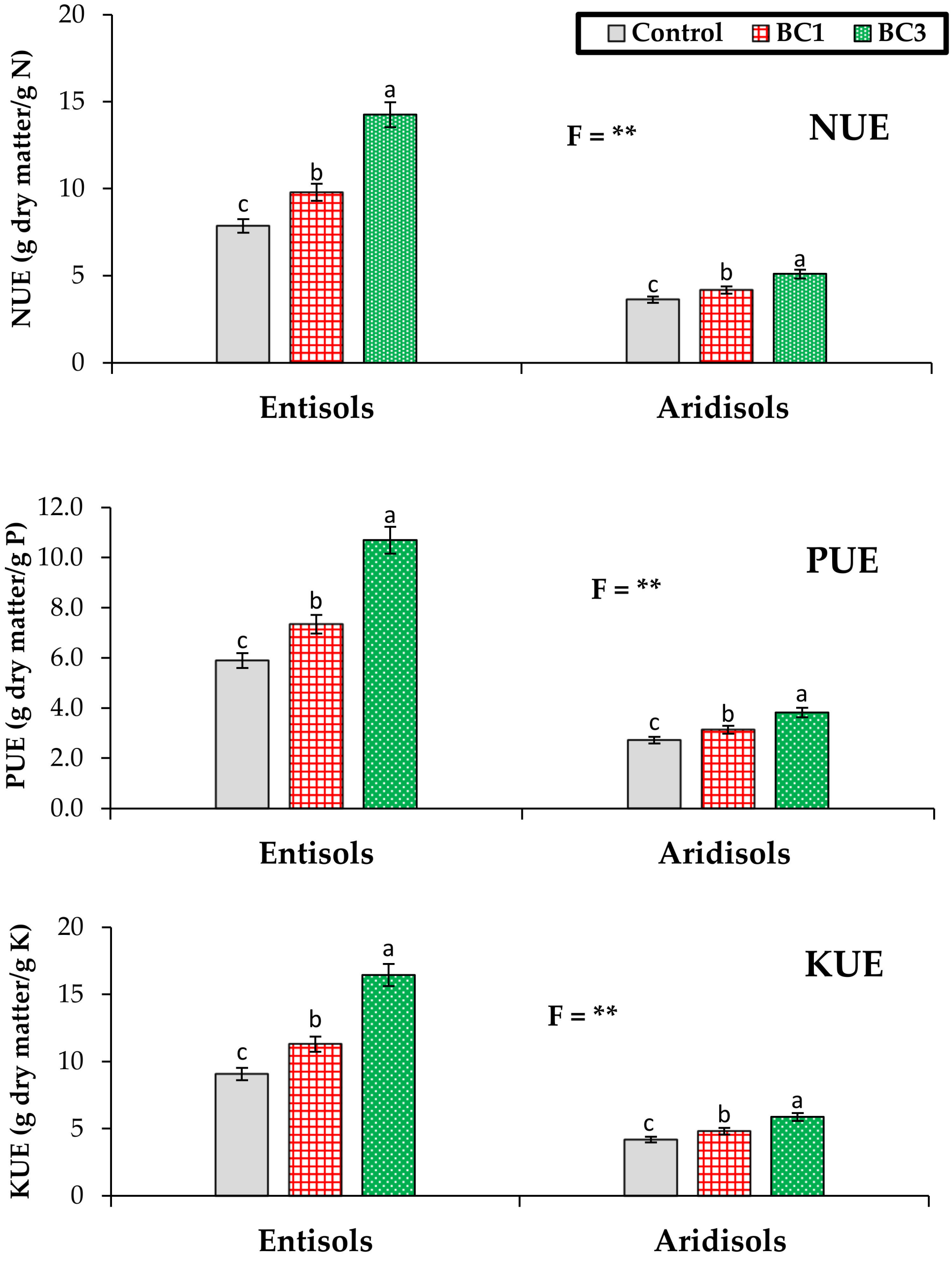

Figure 3. Effect of biochar application on nutrients' use efficiencies. NUE = nitrogen use efficiency. PUE = phosphorus use efficiency. KUE = potassium use efficiency. BC_1 = 1% biochar. BC_3 = 3% biochar (*w*/*w*). Means denoted by the same letter indicate no significant difference according to Duncan's test at $p < 0.05$. F = the ANOVA results between the two soil types, * $p < 0.05$ and ** $p < 0.01$.

4. Discussion

The addition of biochar to the saline-irrigated quinoa increased the plant growth and improved the soil properties. Biochar addition led to clear increases in the nutrients' uptake, the synthesis of photosynthesis pigments, improvement in the soil characteristics, and improvement in nutrients' use efficiency. The soil quality parameters, e.g., pH, salinity, and soil organic matter (SOM), are the key factors that determine the activity of soil microorganisms and enzymes, which directly or indirectly affects plant growth [33–39]. In the current study, biochar additions increased the soil pH with the increasing application levels. This result may be because of the alkaline nature of the biochar that led to exchanging H^+ with the surrounding soil colloids, causing soil pH to rise. Biochar can increase the soil pH thanks to its high pH value [35–38]. The initial value of biochar pH was 11.38. Similar changes in soil pH after biochar application have also been observed by Awad et al. [38], Xu et al. [39], Sheng, and Zhu [40]. The addition of biochar increased the soil organic matter in the two studied soils. The organic carbon compounds in biochar are more stable and resistant to the decomposition by soil microorganisms [23,34,41]. Besides improving nutrient retention, BC has a role in the improvement of the overall soil structure [41–52].

An increase in the availability and uptake of nutrient was reported in the current study. This can be attributed to the nutrient content of BC itself and increased the plant nutrient availability [34,42]. Moreover, the large surface area and high porosity of biochar increased plant water and nutrient use thus enhance crop growth [43,44]. A similar result was found in available N, P, and K for maize and soybean plants [43,45]. Another possible explanation for the increased N, P, and K uptake from biochar treatments could be that biochar adds nutrients to the soil. However, the reduction in the availability of P as a result of BC application could be due to the P retention on biochar surfaces through the function groups and/or high calcium carbonate content and calcium chloride in saline water irrigation. Biochar CEC plays an important role with regard to nutrient retention and plant availability, especially for sandy soils [46].

Biochar amendment resulted in greater shoot, root, and overall biomass than unamended ones [13,47]. Sufficient availability of plant nutrients might have played an important role in the synthesis of photosynthetic pigments such as Chl-a, Chl-b, total Chl (a+b), and carotenoids and growth regulating hormones [48]. Our findings are supported by earlier research where plant growth parameters were increased as a result of biochar application [53–60].

Supplying the soil with an adequate amount of nutrients and their uptake by plants is considered proof of the soil capacity and an increase in the use efficiency [50–54,61–65]. The application of BC has many additional benefits for plant nutrient cycling, high retention, leaching reduction, and increased use efficiency, thereby improving soil fertility [35]. Biochar as an organic amendment improves the level of soil organic matter, which helps to maintain water and nutrient retention, contributing to the sustainability of the cropping systems and higher nutrient use efficiency [34]. Moreover, biochar could store nutrients and be used as a slow-release fertilizer [50,51] thanks to its specific properties such as pore structure and functional groups [50,51,56,66–68]. Some inorganic forms of N can be adsorbed to BC and minimize the emission of ammonia and nitrate leaching from soil [23]. The addition of BC can potentially allow the slow release of nutrients to the plant roots and increase the nutrient use efficiency [23,34,51,52,69]. Owing to the internal reactive surface area of the soil–biochar matrix, the decrease in nutrient leaching is related to increased nutrient use efficiency via an increase in water-soluble nutrients and their retention and, consequently, their availability [23,52,57,70].

5. Conclusions

In the current study, biochar was added to quinoa plants cultivated in pots and irrigated with saline water (EC = 10 dS m^{-1}). Based on the present study, the application of biochar improves some soil properties, with varied effects for each soil type. The modification of agricultural soils containing biochar from crops waste had variable effects on soil properties depending on the soil type and rate of modification. An increase in the dry matter, chlorophyll, carotenoid, and nutrient use efficiency confirms that there is a significant improvement due to the biochar, which has a beneficial effect on quinoa growth under saline conditions. The magnitude improvements were more declared in the Aridisols soils than in the Entisols soils. Aridisols soils were poorer in terms of their content of nutrients and organic matter than Entisols, so they responded clearly to the addition of biochar, which led to a noticeable improvement in their content of organic carbon and nutrients' availability. The current study shows that biochar can improve soil management when it is irrigated by saline water. Moreover, biochar can be used as a soil amendment in arid and semi-arid regions. The efficiency of the use of nutrients by quinoa is greatly improved as a result of adding corn cob biochar. The results of the current study open the way for the use of saline water to irrigate quinoa plants in arid and semi-arid areas, in order to produce food to meet population growth and limited fresh water resources. Further field studies are required to study the response of quinoa plants to saline water under different environmental conditions.

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References

1. ICARDA. International Center for Agricultural Research in the Dry Areas Water and agriculture in Egypt. In Proceedings of the Technical Paper Based on the Egypt Australia-ICARDA Work Shop on On-Farm Water Use Efficiency, Cairo, Egypt, 26–29 June 2011.
2. Govers, G.; Merckx, R.; Van Wesemael, B.; Van Oost, K. Soil conservation in the 21st century: Why we need smart agricultural intensification. *Soil* **2017**, *3*, 45–59. [CrossRef]
3. Alfarrah, N.; Walraevens, K. Groundwater Overexploitation and Seawater Intrusion in Coastal Areas of Arid and Semi-Arid Regions. *Water* **2018**, *10*, 143. [CrossRef]
4. Wrb IWG. *World Reference Base for Soil Resources 2014. International Soil classification System for Naming Soils and Creating Legends for Soil Maps*; FAO: Rome, Italy, 2014; Volume 106.
5. Yost, J.L.; Hartemink, A.E. Soil organic carbon in sandy soils: A review. *Adv. Agron.* **2019**, *217*, 217–310. [CrossRef]
6. El-Desoky, M.A.; Abd ElRazek, M.; Ibrahim, M.S.; Hdad, H.M. Irrigation management of saline ground water for quinoa grown on a sandy calcareous soil. In Proceedings of the Eleventh International Water Technology Conference, IWTC11 2007, Sharm El-Sheikh, Egypt, 15–18 March 2007.
7. FAO. *The State of the World's Land and Water Resources for Food and Agriculture (SOLAW)—Managing Systems at Risk*; Food and Agriculture Organization of the United Nations: Rome, Italy; Earthscan: London, UK, 2011. Available online: http://www.fao.org/docrep/017/i1688e/i1688e.pdf (accessed on 28 December 2016).
8. Khalifa, N.; Yousef, L. A Short Report on Changes of Quality Indicators for a Sandy Textured Soil after Treatment with Biochar Produced from Fronds of Date Palm. *Energy Procedia* **2015**, *74*, 960–965. [CrossRef]
9. Furtad, B.U.; Nagy, I.; Asp, T.; Tyburski, J.; Skorupa, M.; Gołębiewski, M.; Hulisz, P.; Hrynkiewicz, K. Transcriptome profiling and environmental linkage to salinity across Salicornia europaea vegetation. *BMC Plant Biol.* **2019**, *19*, 427. [CrossRef] [PubMed]
10. Angeli, V.; Silva, M.P.; Crispim Massuela, D.; Khan, M.W.; Hamar, A.; Khajehei, F.; Graeff-Hönninger, S.; Piatti, C. Quinoa (*Chenopodium quinoa* Willd.): An Overview of the Potentials of the "Golden Grain" and Socio-Economic and Environmental Aspects of Its Cultivation and Marketization. *Foods* **2020**, *9*, 216. [CrossRef]
11. Hinojosa, L.; González, J.A.; Barrios-Masias, F.H.; Fuentes, F.; Murphy, K.M. Quinoa Abiotic Stress Responses: A Review. *Plants* **2018**, *7*, 106. [CrossRef]
12. Tenic, E.; Ghogareh, R.; Dhingra, A. Biochar—A Panacea for Agriculture or Just Carbon? Preprints. *Horticulturae* **2020**, *6*, 37. [CrossRef]
13. El-Naggar, A.; Lee, S.S.; Rinklebe, J.; Farooq, M.; Song, H.; Sarmah, A.K.; Ok, Y.S. Biochar application to low fertility soils: A review of current status, and future prospects. *Geoderma* **2019**, *337*, 536–554. [CrossRef]
14. Alotaibi, K.D.; Schoenau, J.J. Addition of Biochar to a Sandy Desert Soil: Effect on Crop Growth, Water Retention and Selected Properties. *Agronomy* **2019**, *9*, 327. [CrossRef]
15. Mukherjee, A.; Zimmerman, A.R. Organic carbon and nutrient release from a range of laboratory-produced biochars and biochar–soil mixtures. *Geoderma* **2013**, *193*, 122–130. [CrossRef]
16. Akhtar, S.S.; Andersen, M.N.; Liu, F. Residual effects of biochar on improving growth, physiology and yield of wheat under salt stress. *Agric. Water Manag.* **2015**, *158*, 61–68. [CrossRef]

17. Somerville, P.D.; Farrell, C.; May, P.B.; Livesley, S.J. Biochar and compost equally improve urban soil physical and biological properties and tree growth, with no added benefit in combination. *Sci. Total Environ.* **2020**, *706*, 135736. [CrossRef]
18. Spokas, K.A.; Cantrell, K.B.; Novak, J.M.; Archer, D.W.; Ippolito, J.A.; Collins, H.P.; Boateng, A.A.; Lima, A.A.; Lamb, M.C.; McAloon, A.J.; et al. Biochar: A Synthesis of Its Agronomic Impact beyond Carbon Sequestration. *J. Environ. Qual.* **2012**, *41*, 973–989. [CrossRef]
19. El-Naggar, A.H.; Usman, A.R.; Al-Omran, A.; Ok, Y.S.; Ahmad, M.; Al-Wabel, M.I. Carbon mineralization and nutrient availability in calcareous sandy soils amended with woody waste biochar. *Chemosphere* **2015**, *138*, 67–73. [CrossRef] [PubMed]
20. Lehmann, J.; Rillig, M.C.; Thies, J.; Masiello, C.A.; Hockaday, W.C.; Crowley, D. Biochar effects on soil biota—A review. *Soil Biol. Biochem.* **2011**, *43*, 1812–1836. [CrossRef]
21. Rawat, J.; Saxena, J.; Sanwal, P. Biochar: A Sustainable Approach for Improving Plant Growth and Soil Properties. In *Biochar—An Imperative Amendment for Soil and the Environment*; IntechOpen: London, UK, 2019. [CrossRef]
22. Dahlawi, S.S.; Naeem, A.; Rengel, Z.; Ravi, N. Biochar application for the remediation of salt-affected soils: Challenges and opportunities. *Sci. Total Environ.* **2018**, *625*, 320–335. [CrossRef]
23. Ding, Z.; Zhou, Z.; Lin, X.; Zhao, F.; Wang, B.; Lin, F.; Ge, Y.; Eissa, M.A. Biochar impacts on NH3-volatilization kinetics and growth of sweet basil (*Ocimum basilicum* L.) under saline conditions. *Ind. Crop Prod.* **2020**, *157*, 11290. [CrossRef]
24. Matthiessen, M.K.; Larney, F.J.; Selinger, L.B.; Olson, A.F. Influence of Loss-on-Ignition Temperature and Heating Time on Ash Content of Compost and Manure. *Commun. Soil Sci. Plant Anal.* **2005**, *36*, 2561–2573. [CrossRef]
25. Burt, R. *Soil Survey Laboratory Methods Manual*; Soil Survey Investigations Report, No. 42, Version 4.0; Natural Resources Conservation Service, United States Department of Agriculture: Washington, DC, USA, 2004.
26. Parkinson, J.A.; Allen, S.E. A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological materials. *Commun. Soil Sci. Plant Anal.* **1975**, *6*, 1–11. [CrossRef]
27. Soil Survey Staff. *Keys to Soil Taxonomy*, 11th ed.; USDA-Natural Resources Conservation Services: Washington, DC, USA, 2016.
28. Page, A.L. *Methods of Soil analysis: Chemical and Microbiological Properties*, 2nd ed.; American Society of Agronomy Inc. Soil Science Society of America Journal: Madison, WI, USA, 1982.
29. Lichtenthaler, H.K. Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. In *Methods in Enzymology*; Academic Press: Cambridge, MA, USA, 1987; Volume 148, pp. 350–382.
30. Jackson, M.L. *Soil Chemical Analysis*; Prentice-Hall, Inc.: Englewood Cliffs, NJ, USA; New Delhi, India, 1973.
31. Hesse, P.R. *A Textbook of Soil Chemical Analysis*; CBS Publishers & Distributors: Delhi, India, 1998.
32. Olsen, S.R.; Cole, C.V.; Watanabe, F.S.; Dean, L.A. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. Circular 939*; United States Department of Agriculture: Washington, DC, USA, 1954.
33. Zornoza, R.; Moreno-Barriga, F.; Acosta, J.R.; Muñoz, M.A.; Faz, A. Stability, nutrient availability and hydrophobicity of biochars derived from manure, crop residues, and municipal solid waste for their use as soil amendments. *Chemosphere* **2016**, *144*, 122–130. [CrossRef] [PubMed]
34. Liu, J.; Jiang, B.; Shen, J.; Zhu, X.; Yi, W.; Li, Y.; Wu, J. Contrasting effects of straw and straw-derived biochar applications on soil carbon accumulation and nitrogen use efficiency in double-rice cropping systems. *Agric. Ecosyst. Environ.* **2021**, *311*, 107286. [CrossRef]
35. Randolph, P.; Bansode, R.R.; Hassan, O.A.; Rehrah, D.; Ravella, R.; Reddy, M.; Watts, D.W.; Novak, J.M.; Ahmedna, M. Effect of biochars produced from solid organic municipal waste on soil quality parameters. *J. Environ. Manag.* **2017**, *192*, 271–280. [CrossRef]
36. Rekaby, S.A.; Awad, M.Y.; Hegab, S.A.; Eissa, M.A. Effect of some organic amendments on quinoa plants under saline condition. *J. Plant Nutr.* **2020**, *43*, 1840–1851. [CrossRef]
37. Awad, M.; Liu, Z.; Skalicky, M.; Dessoky, E.S.; Brestic, M.; Mbarki, S.; Rastogi, A.; EL Sabagh, A. Fractionation of Heavy Metals in Multi-Contaminated Soil Treated with Biochar Using the Sequential Extraction Procedure. *Biomolecules* **2021**, *11*, 448. [CrossRef]
38. Awad, M.; Moustafa-Farag, M.; Wei, L.; Huang, Q.; Liu, Z. Effect of garden waste biochar on the bioavailability of heavy metals and growth of *Brassica juncea* (L.) in a multi-contaminated soil. *Arab. J. Geosci.* **2020**, *13*, 439. [CrossRef]
39. Xu, N.; Tan, G.; Wang, H.; Gai, X. Effect of biochar additions to soil on nitrogen leaching, microbial biomass and bacterial community structure. *Eur. J. Soil Biol.* **2016**, *74*, 1–8. [CrossRef]
40. Sheng, Y.; Zhu, L. Biochar alters microbial community and carbon sequestration potential across different soil pH. *Sci. Total. Environ.* **2018**, *622*, 1391–1399. [CrossRef]
41. Joseph, U.E.; Toluwase, A.O.; Kehinde, E.O.; Omasan, E.; Tolulope, A.Y.; George, O.O.; Zhao, C.; Hongyan, W. Effect of biochar on soil structure and storage of soil organic carbon and nitrogen in the aggregate fractions of an Albic soil. *Arch. Agron. Soil Sci.* **2019**, *66*, 1–12. [CrossRef]
42. Shepherd, J.G.; Buss, W.; Sohi, S.P.; Heal, K.V. Bioavailability of phosphorus, other nutrients and potentially toxic elements from marginal biomass-derived biochar assessed in quinoa (*Hordeum vulgare*) growth experiments. *Sci. Total Environ.* **2017**, *584*, 448–457. [CrossRef] [PubMed]
43. Major, J.; Rondon, M.; Molina, D.; Riha, S.J.; Lehmann, J. Maize yield and nutrition during 4 years after biochar application to a Colombia savanna oxisol. *Plant Soil* **2010**, *333*, 117–128. [CrossRef]

44. Sial, T.A.; Lan, Z.; Khan, M.N.; Zhao, Y.; Kumbhar, F.; Liu, J.; Zhang, A.; Hill, R.L.; Lahori, A.H.; Memon, M. Evaluation of orange peel waste and its biochar on greenhouse gas emissions and soil biochemical properties within a loess soil. *Waste Manag.* **2019**, *87*, 125–134. [CrossRef] [PubMed]
45. Suddick, E.C.; Six, J. An estimation of annual nitrous oxide emissions and soil quality following the amendment of high temperature walnut shell biochar and compost to a small scale vegetable crop rotation. *Sci. Total Environ.* **2013**, *465*, 298–307. [CrossRef]
46. Gwenzi, W.; Chaukura, N.; Mukome, F.N.; Machado, S.; Nyamasoka, B. Biochar production and applications in sub-Saharan Africa: Opportunities, constraints, risks and uncertainties. *J. Environ. Manag.* **2015**, *150*, 250–261. [CrossRef]
47. Rogovska, N.; Laird, D.A.; Rathke, S.J.; Karlen, D.L. Biochar impact on Midwestern Mollisols and maize nutrient availability. *Geoderma* **2014**, *230-231*, 340–347. [CrossRef]
48. Chan, K.Y.; Xu, Z. Biochar: Nutrient properties and their enhancement. In *Biochar for Environmental Management: Science and Technology*; Lehmann, J., Joseph, S., Eds.; Earthscan: London, UK, 2009; pp. 67–84.
49. Adekayode, F.; Olojugba, M. The utilization of wood ash as manure to reduce the use of mineral fertilizer for improved performance of maize (*Zea mays* L.) as measured in the chlorophyll content and grain yield. *J. Soil Sci. Environ. Manag.* **2010**, *1*, 40–45.
50. Ding, Y.; Liu, Y.; Liu, S.; Li, Z.; Tan, X.; Huang, X.; Zeng, G.; Zhou, L.; Zheng, B. Biochar to improve soil fertility. A review. *Agron. Sustain. Dev.* **2016**, *36*, 1–18. [CrossRef]
51. Liu, D.; Ding, Z.; Ali, E.F.; Kheir, A.M.S.; Eissa, M.A.; Ibrahim, O.H. Biochar and compost enhance soil quality and growth of roselle (*Hibiscus sabdariffa* L.) under saline conditions. *Sci. Rep.* **2021**, *11*, 8739. [CrossRef]
52. Haider, G.; Steffens, D.; Moser, G.; Müller, C.; Kammann, C.I. Biochar reduced nitrate leaching and improved soil moisture content without yield improvements in a four-year field study. *Agric. Ecosyst. Environ.* **2017**, *237*, 80–94. [CrossRef]
53. Abou-Zaid, E.A.; Eissa, M.A. Thompson Seedless Grapevines Growth and Quality as Affected by Glutamic Acid, Vitamin B, and Algae. *J. Soil Sci. Plant Nutr.* **2019**, *19*, 725–733. [CrossRef]
54. Ali, A.M.; Awad, M.Y.M.; Hegab, S.A.; Gawad, A.M.A.E.; Eissa, M.A. Effect of potassium solubilizing bacteria (*Bacillus cereus*) on growth and yield of potato. *J. Plant Nutr.* **2021**, *44*, 411–420. [CrossRef]
55. Eissa, M.A. Effect of Compost and Biochar on Heavy Metals Phytostabilization by the Halophytic Plant Old Man Saltbush [*Atriplex Nummularia* Lindl]. *Soil Sediment Contam. Int. J.* **2019**, *28*, 135–147. [CrossRef]
56. Eissa, M.A.; Abeed, A.H. Growth and biochemical changes in quail bush (*Atriplex lentiformis* (Torr.) S.Wats) under Cd stress. *Environ. Sci. Pollut. Res.* **2019**, *26*, 628–635. [CrossRef]
57. Al-Sayed, H.; Hegab, S.A.; Youssef, M.; Khalafalla, M.; Almaroai, Y.A.; Ding, Z.; Eissa, M.A. Evaluation of quality and growth of roselle (*Hibiscus sabdariffa* L.) as affected by bio-fertilizers. *J. Plant Nutr.* **2020**, *43*, 1025–1035. [CrossRef]
58. Hajihashemi, S.; Skalicky, M.; Brestic, M.; Pavla, V. Cross-talk between nitric oxide, hydrogen peroxide and calcium in salt-stressed Chenopodium quinoa Willd. At seed germination stage. *Plant Physiol. Biochem.* **2020**, *154*, 657–664. [CrossRef] [PubMed]
59. Noulas, C.; Tziouvalekas, M.; Vlachostergios, D.; Baxevanos, D.; Karyotis, T.; Iliadis, C. Adaptation, agronomic potential, and current perspectives of quinoa under mediterranean conditions: Case studies from the lowlands of central Greece. *Commun. Soil Sci. Plant Anal.* **2017**, *48*, 2612–2629.
60. Gu, M.F.; Li, N.; Shao, T.Y.; Long, X.H.; Brestič, M.; Shao, H.B.; Li, J.B. Accumulation capacity of ions in cabbage (*Brassica oleracea* L.) supplied with sea water. *Plant Soil Environ.* **2016**, *62*, 314–320.
61. Fghire, R.; Anaya, F.; Ali, O.I.; Benlhabib, O.; Ragab, R.; Wahbi, S. Physiological and photosynthetic response of quinoa to drought stress. *Chil. J. Agric. Res.* **2015**, *75*, 174–183. [CrossRef]
62. Yan, K.; Shao, H.; Shao, C.; Chen, P.; Zhao, S.; Brestic, M.; Chen, X. Physiological adaptive mechanisms of plants grown in saline soil and implications for sustainable saline agriculture in coastal zone. *Acta Physiol. Plant.* **2013**, *35*, 2867–2878. [CrossRef]
63. Eissa, M.A.; Roshdy, N.M.K.A. Nitrogen fertilization: Effect on Cd-phytoextraction by the halophytic plant quail bush [*Atriplex lentiformis* (Torr.) S. Wats]. *S. Afr. J. Bot.* **2018**, *115*, 126–131. [CrossRef]
64. Eissa, M.A.; Ahmed, E.M. Nitrogen and Phosphorus Fertilization for some Atriplex Plants Grown on Metal-contaminated Soils. *Soil Sediment Contam. Int. J.* **2016**, *25*, 431–442. [CrossRef]
65. Tian, C.; Zhou, X.; Ding, Z.; Liu, Q.; Xie, G.; Peng, J.; Rong, X.; Zhang, Y.; Yang, Y.; Eissa, M.A. Controlled-release N fertilizer to mitigate ammonia volatilization from double-cropping rice. *Nutr. Cycl. Agroecosyst.* **2021**, *119*, 123–137. [CrossRef]
66. Eissa, M.A.; Nasralla, N.N.; Gomah, N.H.; Osman, D.M.; El-Derwy, Y.M. Evaluation of natural fertilizer extracted from expired dairy products as a soil amendment. *J. Soil Sci. Plant Nutr.* **2018**, *18*, 694–704. [CrossRef]
67. Eissa, M.A.; Almaroai, Y.A. Phytoremediation Capacity of Some Forage Plants Grown on a Metals-Contaminated Soil. *Soil Sediment Contam. Int. J.* **2019**, *28*, 569–581. [CrossRef]
68. Ali, E.F.; Al-Yasi, H.M.; Kheir, A.M.; Eissa, M.A. Effect of Biochar on CO_2 Sequestration and Productivity of Pearl Millet Plants Grown in Saline Sodic Soils. *J. Soil Sci. Plant Nutr.* **2021**, *21*, 897–907. [CrossRef]
69. Alharbi, S.; Majrashi, A.; Ghoneim, A.M.; Ali, E.F.; Modahish, A.S.; Hassan, F.A.; Eissa, M.A. A New Method to Recycle Dairy Waste for the Nutrition of Wheat Plants. *Agronomy* **2021**, *11*, 840. [CrossRef]
70. Abeed, A.H.; Eissa, M.A.; Abdel-Wahab, D.A. Effect of Exogenously Applied Jasmonic Acid and Kinetin on Drought Tolerance of Wheat Cultivars Based on Morpho-Physiological Evaluation. *J. Soil Sci. Plant Nutr.* **2021**, *21*, 131–144. [CrossRef]