sustainability

MDPI

Article

Impact of Biochar as a Soil Conditioner to Improve the Soil Properties of Saline Soil and Productivity of Tomato

Md. Zonayet [1], Alok Kumar Paul [2], Md. Faisal-E-Alam [3], Khalid Syfullah [4], Rui Alexandre Castanho [5,6,*] and Daniel Meyer [6]

[1] Department of Soil Science, Khulna Agricultural University, Khulna 9202, Bangladesh
[2] Department of Soil Science, Sher-e-Bangla Agricultural University, Dhaka 1207, Bangladesh
[3] Department of Management Studies, Begum Rokeya University, Rangpur 5404, Bangladesh
[4] Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka 1207, Bangladesh
[5] Faculty of Applied Sciences, WSB University, 41-300 Dabrowa Górnicza, Poland
[6] College of Business and Economics, University of Johannesburg, Auckland Park, P.O. Box 524, Johannesburg 2006, South Africa
* Correspondence: acastanho@wsb.edu.pl

Abstract: Biochar increases crop yield, soil reliability, and carbon sequestration. This study examined how biochar affected soil properties and tomato yield in saline soil. The experiment was conducted in areas surrounding Khulna Agricultural University and in farmers' fields close to Khulna, Bangladesh. The experiment's layout was a randomized complete block design (RCBD). Tomato cultivation with eight treatments and three replications used biochar with the recommended fertilizer dose (RFD). Using biochar in saline soil significantly influenced tomato growth and yield character. Days after planting, plant height was dramatically impacted by various biochar treatment levels. The height of tomato plants ranged from 65.38 to 46.37 cm, yielding 49.23 tons per hectare. The experiments used biochar treatments to grow more tomatoes than traditional fertilizers and a control treatment. Compared with control treatments, biochar also changed the properties of salty soil after it was harvested. The soil's pH is 6.51 and its particle density is highest at 2.65. The control treatments had the highest EC value, which was 2800, and the biochar application treatments had the lowest EC values. At 100 s/cm, the EC value made the soil 0.6 ppt saltier in the control treatment without biochar, but adding biochar made the soil 0.1 ppt less salty. The percentages of carbon, nitrogen, and organic matter were also the highest that they had been (1.88%, 1.073%, and 2.58%, respectively). The phosphorus concentration in the soil was 19.47 g/g after harvesting. The majority of K and S values used to treat salty soils are interchangeable. Significant changes in tomato growth, yield, and soil properties occurred when biochar was combined with recommended fertilizer doses and applied to saline soil for tomato cultivation.

Keywords: biochar; growth of tomato; yield of tomato; soil properties; soil fertility

Citation: Zonayet, M.; Paul, A.K.; Faisal-E-Alam, M.; Syfullah, K.; Castanho, R.A.; Meyer, D. Impact of Biochar as a Soil Conditioner to Improve the Soil Properties of Saline Soil and Productivity of Tomato. *Sustainability* **2023**, *15*, 4832. https://doi.org/10.3390/su15064832

Academic Editor: Yongrok Choi

Received: 11 February 2023
Revised: 3 March 2023
Accepted: 6 March 2023
Published: 8 March 2023

1. Introduction

One of the most significant challenges facing farmers worldwide is the intrusion of salt into the soil. The southwest coastal region of Bangladesh already faces a significant challenge with soil salinity due to the effects of tidal forces, storm surges, and the spread of increasing salinity levels in river water [1]. The effects of salinity are most noticeable in the land and water near the coast, and due to changes in the climate, it is slowly moving in land and polluting both the water and the land. Bangladesh's coastal areas could see a slow but steady rise in salinity in the future. This is a big problem for both the primary production system and the coastal biodiversity [2]. More than thirty percent of Bangladesh's arable land is located along its coasts. Those areas are extremely fertile. During the past four decades, various degrees of salinity have impacted approximately 0.223 million ha, or 26.7 percent, of newly created land [3]. Problems that arise from the soil are one of the most significant obstacles in the way of crop production in the southern region. The negative effects of salinity have significantly hindered agricultural product production [4].

Eighty percent of Bangladesh is made up of alluvial sediments carried there by rivers like the Ganges, Brahmaputra, Tista, Jamuna, and Meghna, making the country a delta [5]. Salinity harms approximately 53% of the coasts, resulting in an adverse environment and hydrological situation that limits normal crop production all year [6]. As a result of tidal flooding during the wet season (June–October), direct inundation by salty water, and the upward movement of salty groundwater, the coastal areas of Bangladesh are becoming increasingly salty. As the ground dries out, the problem worsens [7].

These regions have a shallow level of agricultural land use, which is significantly lower than the average cropping intensity across the country. The presence of salinity creates unfavorable environmental conditions and hydrological conditions, both of which inhibit the normal production of crops throughout the year [8]. The salinity problem in Bangladesh is becoming even more severe as soil salinity rises. This causes a decline in yield or, in extreme cases, a complete loss of yield, depending on the level of salinity present during the stages of plant growth [9]. Soil reaction values (pH) along the coast can take on a range from 6.0 to 8.4. Soils typically have between 1% and 1.5% organic matter. Salty soils typically have severe nitrogen (N) and phosphorus (P) deficiencies [4].

Soil with superior structure, bulk density, porosity, and hydraulic conductivity leads to increased harvests. Improved root development, water and nutrient retention, and soil profile movement are all possible thanks to these soil features [10]. Biochar is a viable option in relation to modifying soil's physical properties [11]. Biochar, a solid substance, is made through a process called pyrolysis. In pyrolysis, biomass of many different biological origins is thermally decomposed. Biochar is an organic material with a high carbon content and fine grains created through heat decomposition. Agricultural ecosystems incorporating biochar have gained significant interest over the past few decades due to its potentially positive effects on crop productivity [12]. Biochar's potential for reducing GHG emissions, storing carbon in soil, restoring degraded soils, and reducing the use of chemical fertilizers in agriculture is enormous. Additionally, it improves the soil's corporeal contaminant and properties, stimulating plant growth [13].

As reported (Albert et al., 2018) [14], biochar application enhances soil quality by lowering pH, increasing water-holding capacity, promoting the growth of more beneficial fungi and microorganisms, enhancing cation exchange capacity, and preserving nutrient levels. Due to their high adsorptive capacity [15], biochar amendments effectively increase soil nutrient availability. Treating the soil particles with biochar makes it possible to increase the capillary force of the soil and its capacity to retain water [16], using biochar to lessen the soil's salinity and loss of nutrients [17]. Some soil chemical properties, such as pH, available phosphorus, soil organic carbon, and potassium were significantly (p 0.05) increased by the co-applied biochar with compost and NPK fertilizer [18]. Biochar application not only increased plant nutrient concentration and uptake [19] but also significantly improved crop growth parameters of tomato plants (i.e., plant height, fresh plant weight, and dry biomass).

The most remarkable effects of biochar have been discovered in highly weathered, acidic soils. Few studies have been conducted on biochar in alkaline soils and the ones that have been conducted typically show that it has little or no effect. One of the reasons for this is that biochar can raise the pH of the soil, especially when it has been heated to a high temperature. As a result, biochar may also be useful in alkaline soils, provided that the appropriate kind of biochar is utilized in such situations [20]. Tomatoes are among the most valuable vegetable crops because they can survive in soil with moderate salt. In addition, it is one of the most widespread agricultural products in salty climates. High salt levels, however, are seriously interfering with the development of the tomato crop at every stage, leading to a marked reduction in crop yield. Tomato yields were significantly higher in charcoal-treated beds compared with non-charcoal-treated beds [21]. Using biochar increased vegetable yields by 4.7% to 25% when compared with conventional farming methods [22].

The tomato (*Solanum lycopersicum* L.) is a popular food crop not only in Bangladesh but also all over the world. Its versatility as a fresh and processed fruit contributes to its high commercial value [23]. Tomatoes are grown in many salt-polluted regions because of their moderate salt tolerance. Salinity can positively modulate tomato fruit metabolism, which increases the production's sensorial and nutritional value. Solanaceous plants use tomatoes as a model crop. So, any discoveries made in the lab about tomatoes could theoretically be applied to other high-value cash crops such as pepper, eggplant, and potatoes [24]. Nonetheless, increased heat, water stress, and salinity from climate change are expected to have a cumulative reduction ratio on tomato and other vegetable crop yields in Bangladesh.

Biochar has been used as a soil amendment to examine its effects on the soil's physical, chemical, and biological properties, upon which the soil's ability to perform its functions depends [25]. Despite biochar's widespread interest as a soil amendment, most prior research has concentrated on the CEC, pH, nutrient content, plant growth, and carbon sequestration potential of unamended soils [26]. Biochar has been found to have beneficial effects on the soil's microbiota, microbial community, and nutrient status [27]. However, there is scant literature on how biochar alters soil properties and the stress caused by salinity. Due to the paucity of research on the use of biochar in saline soil for tomato production, the results of this experiment will be especially valuable in terms of improving tomato growth, yield, and quality by preserving soil fertility in the face of increasing salinity. This study was conducted to determine the optimal dose of biochar in combination with inorganic fertilizer to maximize tomato production in salinity conditions; to evaluate the efficacy of biochar in reducing soil salinity to increase crop yields; to observe the effect of biochar on soil properties such as bulk density, particle density, soil porosity, pH, and EC both before and after crop harvesting; and to conduct an analysis of the variance of the data.

2. Materials and Methods

The purpose of this research was to determine if adding biochar to the soil would have any effect on the salinity levels there, thus increasing tomato yields. This section provides a concise summary of the following aspects of the experiment: time frame, location description, soil and climate of experimental area, crop or planting materials, treatments, experimental design and layout, growing procedure, intercultural operations, data collection, and statistical analysis. Here is an overview of the specific procedures and experiments that were conducted:

2.1. Study Area

The experiment was conducted from July 2021 to June 2022 in the summer season. The study was carried out in a farmer's field near the Khulna Agricultural University in Khulna, Bangladesh. As part of the AEZ-13 (Ganges Tidal Floodplain) agroecological classification, the experimental site is located in a particularly suitable environment for studying agricultural practices. The experiment site was located at 22.84 degrees north latitude, 89.54 degrees east longitude, and an elevation of 8 m (26 feet) above sea level. In addition to a rapidly expanding population, this region is also vulnerable to various natural and human-exacerbated disasters. Khulna is on the coast, where groundwater is scarce for irrigation due to worries about salt-intruded aquifers. The effects of storm surges and coastal flooding are particularly felt in Bangladesh's coastal regions [28]. The laboratory area is hot and humid during the summer months, while it is comfortably warm in the winter months. The South Asian monsoon has a major impact on the city of Khulna. As a result of its geographical position and the influence of the Sundarbans to the south of the city, Khulna receives significantly less precipitation than other parts of Bangladesh. It receives an average of 1878.4 mm (73.95 in) of precipitation per year, with 87% of that total occurring between May and October. Cyclones that form in the Bay of Bengal also bring heavy rainfall to Khulna. With an annual mean temperature of 26.3 °C (79.3 °F), the city experiences a wide range of temperatures from 11.4 °C (52.5 °F) in the mornings of January to 34.6 °C (94.3 °F) in the afternoons of April [29].

2.2. Soil Characterization

Coastal soil is mostly a non-calcareous, gray floodplain. Dry, acidic soils have acid sulfate. Most soil is alkaline. The relative proportions of sand, silt, and clay in soil texture affect crop production. Clay loam dominates, followed by clay. Soil pH was 7.5 and organic matter was 1.3%. The flat, above-flood-level experimental area had irrigation and drainage. Experimental field soil samples were 0–15 cm deep. pH, organic matter, total N, available P, and exchangeable K were examined. To begin, a hole in the field was dug with an auger to a depth of 0 to 15 cm in order to gather a random sample of soil for analysis of the pre-harvest soil properties. A complex sample was broken down into its parts and simplified. The straightforward sample consisted of 250 g of soil, which were then dried and ground into a powder. This powder was then combined with a sample that we already knew to be from the Soil Resource Development Institute and the sample was analyzed to determine its value.

The instruments, apparatus, and equipment used in determining the bulk density, particle density, soil porosity, soil pH, EC, salinity, organic matter, organic carbon, total N, available P, exchangeable K, and available S are augers, sieves, plastic containers, ovens, electrical balances, spectrophotometers, pH meters, EC meters, and some chemicals. Soil samples from each plot were air-dried, crushed, and passed through a 2 mm (10-mesh) sieve. The soil samples were kept in plastic containers to determine the physical and chemical properties of the soil.

Soil pH was measured with the help of a glass electrode pH meter. Organic carbon in the soil sample was determined by wet oxidation method. The underlying principle was used to oxidize the organic matter with an excess of 1N $K_2Cr_2O_7$ in presence of conc. H_2SO_4 and conc. H_3PO_4 and to titrate the excess $K_2Cr_2O_7$ solution with 1N $FeSO_4$ [30]. The total N content of the soil was determined following the Micro Kjeldahl method. One gram of oven-dry-ground soil sample was taken into a Micro Kjeldahl flask to which 1.1 gm catalyst mixture (K_2SO4: CuSO4. 5H_2O: Se in the ratio of 100:10:1) and 6 mL H_2SO4 were added [30]. Available P was extracted from the soil with 0.5 M $NaHCO_3$ solutions, pH 8.5. Exchangeable K was determined by 1N NH_4OAc (pH 7) extraction methods and by using a flame photometer and was calibrated with a standard curve [31]. Table 1 shows the initial soil's physical and chemical properties.

Table 1. Initial soil physical and chemical properties (0–15 cm depth).

Characteristics	Value
Mechanical fractions: % Sand (2.0–0.02 mm) % Silt (0.02–0.002 mm) % Clay (<0.002 mm)	 29 46 34
Textural class	Sandy to Clay loam
Bulk Density (g/cc)	1.43
Particle Density (g/cc)	2.54
Soil Porosity %	30–40
EC (µS/cm)	2400
pH	7.5
Organic carbon (%)	0.65
Organic matter (%)	1.4
Total N (%)	0.08

Table 1. *Cont.*

Characteristics	Value
Available P (µg/g)	16.73
Exchangeable K (meq/100 g soil)	0.13
Available S (µg/g)	18.32

2.3. Chemical Properties of Biochar, Biochar Production, and Collecting Biochar

Biochar, which is made from biomass like charcoal and agricultural byproducts, was included in our research. Grass and wood are dried at 105 °C before being pyrolyzed at 450 °C for 15 min to create this biochar on a commercial scale. This second reactor, which is stationary, metallic, and cylindrical in shape, holds 60 L. Both of the reactors could only be opened by breaking the seal. Research and Technology Corporation conducted the pyrolysis process. Since it is a byproduct of the expanding biofuel industry and its high silicon content can improve biochar's ability to retain water, we used a variety of woods and grasses. Most of Bangladesh Company's biochar has 1.053% organic carbon and 1.82% organic matter. The Christian Development Board (CCDB) in Shivaloy, Manikgonj, Bangladesh, was the source of our biochar.

2.4. Experimental Details

2.4.1. Treatments and Factor of the Experiment

Treatments: The treatments are as follows:
T1 = Control
T2 = RFD (Recommended Fertilizer Dose: N150 P40 K100 S15 Zn2.5 kg/ha)
T3 = RFD + Biochar @ 1 ton/ha
T4 = RFD + Biochar @ 1.5 ton/ha
T5 = RFD + Biochar @ 2 ton/ha
T6 = 2/3 RFD + Biochar @ 1 ton/ha
T7 = 2/3 RFD + Biochar @ 1.5 ton/ha
T8 = 1/2 RFD + Biochar @ 2 ton/ha

2.4.2. Conception and Plan for Experiments

The study had a randomized complete block design (RCBD) with three independent replicates. Three equal sections divided the 18.5 m by 18 m space. Each plot was 6 square meters (4.0 m by 1.5 m) with one-meter separated plots between blocks and two-meter separated blocks.

2.5. Agricultural Supplies, Preparation of Seedbed, Land Preparation, and Planting Seedlings

Lal Teer Seed Company limited provided the seed for the selected tomato varieties, which was perfect for the warm weather of summer. It has a life cycle of about 95–100 days and produces a typical yield of 25–30 t ha^{-1}. Before scattering them across a modest seedbed, the collected seeds were stored at room temperature. After 10 days in the seedbed, these seedlings were ready to be moved to primary fields. The power tiller was used to break ground on the experimental plot on 11 March 2022. Plowing and cross-plowing were accomplished with a power tiller and then the laddering was completed. The land was prepared for planting by 15 March 2022. Furadan 5G was incorporated into the soil at a rate of 10 kg per hectare to prevent cutworms from damaging the young plants before the plot was plowed.

2.6. Fertilizer Application

A variety of fertilizers including urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum, and zinc sulphate were applied to the test plot. Seven days before planting tomatoes, a basal dose consisting of biochar (in full, as per treatment), triple super phosphate, gypsum, zinc sulfate, and one-half of urea and MoP was applied. The remaining urea and MoP were applied as a side dressing at 35 and 50 DAP [32].

2.7. Plant Protection Measures

As a preventive measure against fungal infection, Dithane M-45 was used at 30 DAP. Ridomil (0.25%) was sprayed on the crop at 45 DAP to protect it from late blight.

2.8. Data Collection

The characteristics of the soil were measured both before and after harvest. Tomatoes are measured for their height, stem diameter, number of fruits per plant, yield in tons per hectare, and finally, yield quality as a percentage.

2.9. Statistical Analysis

Tomatoes' development, harvest, and yield-contributing traits were statistically analyzed to see if increasing or decreasing the biochar application rate had a statistically significant effect. We performed an F test for an analysis of variance after averaging all of the character values. The significance of the difference between the means of the treatment combinations was estimated at a 5% level of probability using Duncan's Multiple Range Test (DMRT) [33]. Some of the statistical analysis and visuals were created in the R studio version (RStudio Team, 2018) [34] and in Microsoft Excel. The assumptions of normality and homogeneity of variances were tested using a 0.05 significance level for both the ANOVA.

3. Results

3.1. Aspects of Crop Development

3.1.1. Plant Height (cm)

The number of days after planting (DAP) significantly impacted the plant height, which was significantly influenced by the different levels of biochar applications (Table 2). The T5 treatment produced the tallest plants (34.12, 47.32, 58.32, 61.28, and 62.43 cm at 30, 45, 60, 75, and 90 DAP, respectively). This treatment was statistically identical to the other treatments. On the other hand, the T1 treatment produced the shortest plants (15.34, 23.23, 31.47, 38.32, 48.11 cm at 30, 45, 60, 75, and 90 DAP, respectively).

Table 2. Effect of Biochar with RFD on plant height (cm) and number of stem hill-1 at different days after planting.

Treatment	Plant Height (cm)										Number of Stem Hill^{-1}	
	30 DAP		45 DAP		60 DAP		75 DAP		90 DAP			
T_1	15.34	c	23.23	f	31.47	f	38.42	f	48.11	e	2.17	c
T_2	27.32	ab	36.55	c	46.38	c	46.32	b	49.77	c	4.00	b
T_3	32.41	ab	45.32	ab	54.32	a	57.12	ab	58.65	b	6.42	a
T_4	30.21	b	39.54	bc	51.55	b	59.56	b	56.38	b	5.98	ab
T_5	34.12	a	47.32	a	58.32	a	61.28	a	62.43	a	6.63	a
T_6	28.65	b	32.45	c	52.41	b	49.53	b	59.45	b	4.91	b
T_7	22.56	b	34.22	b	45.38	c	48.34	e	49.19	c	4.67	ab
T_8	27.21	c	27.67	e	38.45	f	40.76	d	47.95	d	5.89	ab
$LSD_{(0.05)}$	2.35		1.76		1.34		1.68		1.47		2.39	
CV (%)	7.83		8.32		6.43		8.14		6.89		18.45	

Note: a—highest significant, b—less significant than 'a', c—less significant than 'b', d—less significant than 'c', e—less significant than 'd', f—less significant than 'e', g—less significant than 'f', ab—intermediate significant between 'a' and 'b', bc—intermediate significant between 'b' and 'c', cd—intermediate significant between 'c' and 'd'.

3.1.2. Crop Growth, Yield, and Yield Components

Increases in tomato height, stem diameter, and yield were observed, and the correlation between the amount of biochar that was applied and those changes was direct and proportional. However, applying biochar to salty soils showed the best results for tomato height, leaf number, yield, and the soil's chemical and physical properties. Using saline conditions resulted in lower tomato height, leaf number, and yield values.

Since they encourage the development of new leaves and stems, nitrogen, phosphorus, and potassium are the three nutrients necessary to successfully cultivate tomatoes. During the cultivation process, biochar application had a discernible impact on the height of the tomato plants. All of the treatments involving biochar with recommended fertilizer doses observed significantly higher plant heights when compared with the treatment with the normal recommended fertilizer dose and the control treatment. The application of varying concentrations of biochar in conjunction with the recommended amount of fertilizer significantly influenced the overall height of tomato plants. This resulted in a significant increase. The tomato plant reached its greatest measured height of 65.38 to 46.37 cm during the course of the control treatment (Treatment 1), which lasted for the entire experiment.

The maximum number of fruits/plants was also observed in T5 (61.36) (T5 = RFD + Biochar @ 2 ton/ha) treatment receiving biochar with RFD compared with control T1 treatment which was statistically significant. The highest yield of tomatoes came from those experimented on with T5 treatment (49.23 ton/ha) (T5 = RFD + Biochar @ 2 ton/ha), where the lowest yield was found in control treatment T1 (11.87 ton/ha) and RFD treatment T2 (29.56 ton/ha). Biochar with RFD increases the tomato yield in saline soil compared with the control treatment. Biochar application increases the yield of tomatoes experimenting with other treatments, which were statistically similar to T3 (46.87 ton/ha), T6 (38.76 ton/ha), and T7 (42.19 ton/ha) (Table 3).

Table 3. Effect of Biochar with RFD on plant height (cm), no. of fruits/plant, and yield ton/ha over control of tomato cultivation.

Treatments	Plant Height/cm	No of Fruits/Plant	Yield Ton/ha
T_1	46.37 ^{b}	30.12 ^{d}	11.87 ^{g}
T_2	43.9 ^{ab}	39.87 ^{c}	29.56 ^{e}
T_3	56.1 ^{ab}	47.23 ^{ab}	37.15 ^{d}
T_4	57.43 ^{a}	49.11 ^{a}	46.87 ^{ab}
T_5	65.38 ^{a}	61.36 ^{a}	49.23 ^{a}
T_6	51.21 ^{ab}	45.76 ^{a}	38.76 ^{b}
T_7	56.48 ^{ab}	48.23 ^{ab}	42.19 ^{c}
T_8	49.75 ^{a}	49.17 ^{ab}	30.74 ^{f}
$LSD_{(0.05\%)}$	3.23	4.18	1.43
CV %	4.28	9.10	5.37

Note: a—highest significant, b—less significant than 'a', c—less significant than 'b', d—less significant than 'c', e—less significant than 'd', f—less significant than 'e', g—less significant than 'f', ab—intermediate significant between 'a' and 'b', bc—intermediate significant between 'b' and 'c', cd—intermediate significant between 'c' and 'd'.

In the case of Table 4, there was another replication for each of the eight treatments and the results were analyzed using a variance. The error can be calculated using the total value of each replication and treatment, and the coefficient of variance and grand mean, using the ANOVA table. Compared with our control treatment, our desired treatments exhibited a significantly larger degree of variation than the control treatment. Additionally, errors were reduced to a minimum.

Table 4. Randomized Complete Block AOV (analysis of variance) for yield ton/ha of tomato cultivation.

Source of Variation	DF	SS	MS	F	P
Replication	2	12.67	4.987		
Treatment	7	2193.26	265.43	153.29	0.0000
Error	14	37.61	1.54		
Total	23	2643.28			
Grand Mean			32.76		
CV%			4.19		

T1 = Control, T2 = RFD (Recommended Fertilizer Dose: N150 P40 K100 S15 Zn2.5 kg/ha, T3 = RFD + Biochar @ 1 ton/ha, T4 = RFD + Biochar @ 1.5 ton/ha, T5 = RFD + Biochar @ 2 ton/ha, T6 = 2/3 RFD + Biochar @ 1 ton/ha, T7 = 2/3 RFD + Biochar @ 1.5 ton/ha, T8 = 1/2 RFD + Biochar @ 2 ton/ha.

3.2. Grading of Tomato Fruits (% by Number)

The yield of tomatoes has been sorted into marketable (>20 g) and non-marketable (20 g) categories based on their weight. The treatments significantly differed from one another in terms of the quality of the tomatoes that they yielded. T1 = control treatment had the highest percentage of unmarketable fruit yield (20 g), while T5 = (RFD + Biochar @ 2-ton ha^{-1}) had the lowest percentage of unmarketable tuber yield (20 g). In terms of marketable tubers (>20 g), T5 = (RFD + Biochar @ 2-ton ha^{-1}) produced the highest percentage (87.59%), while T1 (control) produced the lowest percentage (28.43%) (Table 5).

Table 5. Effect of biochar on grading of tomato fruits yield (% by number).

Treatments	% no. of Non-Marketable Fruits < 20 g	% No. of Marketable Fruits > 20 g
T_1	78.43 ^{a}	28.43 ^{d}
T_2	30.23 ^{b}	51.47 ^{c}
T_3	25.67 ^{c}	59.37 ^{b}
T_4	27.34 ^{bc}	65.78 ^{b}
T_5	16.89 ^{cd}	87.59 ^{a}
T_6	28.56 ^{b}	54.38 ^{c}
T_7	30.12 ^{cd}	63.59 ^{bc}
T_8	22.89 ^{d}	71.45 ^{b}
CV (%)	12.68	5.94
$LSD_{(0.05)}$	5.49	7.11

Note: a—highest significant, b—less significant than 'a', c—less significant than 'b', d—less significant than 'c', e—less significant than 'd', f—less significant than 'e', g—less significant than 'f', ab—intermediate significant between 'a' and 'b', bc—intermediate significant between 'b' and 'c', cd—intermediate significant between 'c' and 'd'.

3.3. Analyzed Physical and Chemical Properties in Post-Harvest Soil of Tomato Cultivation

3.3.1. Sand, Silt, Clay, and Textural Classes after Harvesting of Tomato Crops in Saline Condition

The relative proportion of sand, silt, and clay is called soil texture. In saline areas, those varied according to climatic conditions. In the dry period, those elements are found less because most of the saline area's soil contains a higher amount of sandy loam; though rainfall is lower in those, so this mixture fraction is not changed. Recently, it has changed significantly due to the cultivation of tomato crops with biochar that it needs to maintain sustainability. After harvesting crops, % of sand, silt, and clay were found to be 22%, 33%, and 59%. Textural classes were found clay.

3.3.2. Impact of Biochar with RFD on Bulk Density, Particle Density, Soil Porosity, Soil pH, EC, and Salinity in Post-Harvest Soil of Tomato Cultivation over Control

The physical and chemical parameters such as pH, electrical conductivity, salinity of soil, particle density, bulk density, organic matter, organic carbon, soil porosity, and concentration of N, P, K, S after harvesting tomatoes in saline soil are presented in Tables 6 and 7.

Table 6. Effect of biochar with RFD on bulk density, particle density, soil porosity, soil pH, EC, and salinity in post-harvest soil of tomato cultivation over control.

Treatments	Bulk Density (g/cc)	Particle Density (g/cc)	Soil Porosity %	Soil pH	EC (µS/cm)	Salinity (ppt)
T_1	1.63 ^{f}	2.65 ^{e}	30.33 ^{g}	7.84 ^{f}	2800	0.6 ^{c}
T_2	1.29 ^{c}	1.98 ^{d}	39.75 ^{bc}	7.13 ^{e}	2400	0.6 ^{c}
T_3	1.19 ^{d}	1.34 ^{bc}	41.65 ^{c}	6.39 ^{bc}	600	0.4 ^{b}
T_4	0.9 ^{b}	1.21 ^{b}	46.54 ^{b}	6.19 ^{cd}	500	0.4 ^{b}
T_5	1.037 ^{a}	1.08 ^{a}	48.65 ^{a}	6.51 ^{a}	100	0.1 ^{a}
T_6	1.08 ^{cd}	1.31 ^{bc}	38.47 ^{d}	6.10 ^{d}	200	0.2 ^{b}
T_7	1.04 ^{e}	1.29 ^{c}	32.21 ^{f}	6.62 ^{b}	600	0.4 ^{a}
T_8	1.12 ^{e}	1.27 ^{c}	33.56 ^{e}	6.23 ^{c}	200	0.2 ^{a}
$LSD_{(0.05)}$	0.098	0.096	1.89	0.085	0.067	0.043
CV (%)	1.007	1.64	1.57	0.081	4.78	1.037

Note: a—highest significant, b—less significant than 'a', c—less significant than 'b', d—less significant than 'c', e—less significant than 'd', f—less significant than 'e', g—less significant than 'f', ab—intermediate significant between 'a' and 'b', bc—intermediate significant between 'b' and 'c', cd—intermediate significant between 'c' and 'd'.

Table 7. Effect of biochar with RFD on organic matter, organic carbon, N, P, K, and S content in post-harvest soil of tomato cultivation over control treatment.

Treatments	Organic Matter (%)	Organic Carbon (%)	Total N (%)	Available P (µg/g)	Exchangeable K (meq/100 g)	Available S (µg/g)
T_1	1.27 ^{g}	1.01 ^{f}	0.084 ^{f}	8.65 ^{f}	0.18	5.14
T_2	1.29 ^{e}	1.39 ^{cd}	0.097 ^{e}	10.34 ^{e}	0.17	5.18
T_3	1.63 ^{c}	1.02 ^{b}	1.000 ^{c}	12.53 ^{d}	0.14	5.19
T_4	2.17 ^{b}	1.56 ^{b}	0.920 ^{b}	15.18 ^{b}	0.14	5.19
T_5	2.58 ^{a}	1.88 ^{a}	1.073 ^{a}	19.47 ^{a}	0.17	5.13
T_6	2.21 ^{b}	1.23 ^{e}	1.042 ^{d}	14.67 ^{c}	0.19	5.13
T_7	1.48 ^{c}	1.47 ^{c}	0.094 ^{e}	13.61 ^{bc}	0.13	5.18
T_8	1.38 ^{d}	1.83 ^{a}	0.890 ^{e}	15.12 ^{b}	0.18	5.13
$LSD_{(0.05)}$	0.068	0.059	0.075	0.067	NS	NS
CV (%)	1.14	1.51	1.83	0.63	5.27	0.74

Note: a—highest significant, b—less significant than 'a', c—less significant than 'b', d—less significant than 'c', e—less significant than 'd', f—less significant than 'e', g—less significant than 'f', ab—intermediate significant between 'a' and 'b', bc—intermediate significant between 'b' and 'c', cd—intermediate significant between 'c' and 'd'.

It was demonstrated that the experiment with the lowest bulk density occurred when biochar was applied at the recommended fertilizer dose (T5 = RFD + Biochar @ 2 tons/ha) and that bulk density was also minimized by using charcoal-type biochar, i.e., 1.08 in comparison with the control T1 treatments' 2.65 g/cc. On the other hand, applying biochar to treated saline soil led to an increase in both the porosity of the soil and its capacity to hold water. When we used biochar before the final stage of land preparation, the biochar acted as a buffer for the soil, keeping the soil's pH in a healthy balance. Therefore, increased quantities of high-quality biochar can also help neutralize the pH of the soil. Analysis of the soil revealed that, except for the control, all treatments were able to maintain the pH of the soil within a relatively stable range. When compared with the control group, the T5 treatments brought about a reduction in both the electrical conductivity and salinity of the soil.

3.3.3. Effect of Biochar with (RFD) on Organic Matter and Organic Carbon (OC) in Saline Soils

There was found to be a significant difference in the organic matter when using biochar. T5 treatment (T5 = RFD + Biochar @ 2 ton/ha) recorded the highest amount of organic matter (2.58), which was statistically identical with T4 treatment (2.17) (T4 = RFD + Biochar @ 1.5 ton/ha) and also statistically similar to T6 treatment (2.21), while T1 treatment (T1 = RFD (Recommended Fertilizer Dose: N150 P40 K100 S15 Zn2.5) recorded the lowest amount. It was reported by (Karim MR et al., 2020) [35] that the soil organic matter contents (%) in the study plots were generally patchy (high standard errors); however, despite the high variability, biochar additions resulted in significantly increased SOM values that persisted through the measurement period.

The biochar clearly had a sizeable effect on organic carbon. T5, which included RFD and biochar, applied at 2 tons per hectare, resulted in the lowest organic carbon yields (0.91). When applied to saline soils alongside the suggested amount of fertilizer, biochar reduces the soil's organic carbon content, subsequently reducing soil compaction and raising the soil's particle density. Among all treatments, the organic carbon content recorded was 1.98 for the T1 treatment. What is meant by "soil organic carbon" is the incorporation of carbon-rich soil amendments with extended mean residence times and slow decay rates (SOC). A high SOC sequestration potential is associated with biochar application due to its long-term stability [36] and the possibility of large-scale production [37,38]. The available biomass is the only constraint on this potential's full realization.

3.3.4. Effect of Biochar with (RFD) on Nutrient Availability in Saline Soils

After harvesting crops, the amounts of organic matter and organic carbon in the soil were significantly affected by RFD's application of biochar at a rate of 2 tons per hectare. The highest concentration of organic matter (2.58%) was found in treatment T5 compared with the control group. Biochar is an important part of the carbon sequestration process regarding organic carbon because biochar profoundly affects organic carbon when used in agriculture. Treatments at the T5 level yielded the highest organic carbon content, at 1.88%, compared with the control T1 sample.

The highest levels of N were found in the T5 treatment with biochar applied alongside the suggested amount of fertilizer. Various treatments had sizable effects on total nitrogen levels. While T1 had the lowest total nitrogen (1.042), T5 (RFD + biochar @ 2 t/ha) had the highest (1.073). To ensure that a lack of phosphorus (P) does not stunt crop production, P management should center on increasing and sustaining sufficient levels of available P in the soil. Given that the effects of applying phosphorus (P) fertilizer can linger for years after application, it is important to implement site-specific, long-term plans to ensure a steady supply of P in the soil. The amount of biochar used in conjunction with the RFD treatment significantly affected the post-harvest soil's available P. T5 had the highest post-harvest soil available (P) at 19.47 g/g. The post-harvest soil with the T1 treatment (no fertilizer and biochar) had the lowest available P levels at 8.65 g/g (control). Most biochar treatments increased P content in saline soil, with T4 (15.18), T6 (14.67), T7 (13.61), and T8 (13.60) showing the greatest increases.

The treatment did not significantly impact the amount of potassium that could be exchanged. It was demonstrated that there is no correlation between treatment T1 and the other treatments that received biochar with RFD in the post-harvest saline soils. Therefore, the post-harvest soil's exchangeable potassium and available sulfur are insignificant. Regarding the remediation of salty soils, the values of potassium and sulfur are almost identical (see Table 7).

3.4. Analysis of Variance of Saline Soil Physical and Chemical Properties

ANOVA's post-harvest soil's physical and chemical properties showed a significant difference in almost all the experiment parameters—Biochar with recommended fertilizers' dose calculated with F value and critical T value. Tomato cultivation with biochar application in saline experimental error is low in the soil's physical properties, but a minimum amount of error was found in chemical properties, i.e., exchangeable K and available S (Tables 8 and 9).

Table 8. Analysis of variance of data (ANOVA) on bulk density, particle density, soil porosity, soil pH, EC, and salinity in post-harvest soil properties.

Source of Variation	df	Bulk Density (g/cc)	Particle Density (g/cc)	Soil Porosity %	Soil pH	EC (µS/cm)	Salinity (ppt)
Replication	2	0.003	0.0019	0.0003	0.006	0.002	0.001
Factor A	7	0.093	0.0032	0.0005	0.007	0.703	0.003
Error	14	0.0063	0.0002	0.0003	0.006	0.006	0.001
Calculated F Value		1.02 *	1.52 *	0.004 *	0.004 *	155.38 *	0.001 *
Critical T Value		5% at 2.154					
		0.129	0.0439	0.0037	0.063	0.175	0.01

* Significant. T_1 = Control, T_2 = RFD (Recommended Fertilizer Dose: N_{150} P_{40} K_{100} S_{15} $Zn_{2.5}$ kg/ha, T_3 = RFD + Biochar @ 1 ton/ha, T_4 = RFD + Biochar @ 1.5 ton/ha, T_5 = RFD + Biochar @ 2 ton/ha, T_6 = ⅔ RFD + Biochar @ 1 ton/ha, T_7 = ⅔ RFD + Biochar @ 1.5 ton/ha, T_8 = ½ RFD + Biochar @ 2 ton/ha.

Table 9. Analysis of variance of data (ANOVA) on organic matter, organic carbon, N, P, K, and S content in post-harvest soil properties.

Source of Variation	df	Organic Matter (%)	Organic Carbon (%)	Total N (%)	Available P (µg/g)	Exchangeable K (meq/100 g)	Available S (µg/g)
Replication	2	0.006	0.0018	0.0001	0.005	0.002	0.002
Factor A	7	0.019	0.0061	0.0007	0.003	0.108	0.002
Error	14	0.014	0.0084	0.0001	0.002	0.002	0.001
Calculated F Value		1.49 *	1.67 *	0.0012 *	0.004 *	NS	NS
Critical T Value		5% at 1.843					
		0.283	0.0754	0.00398	0.00154	0.004	0.0003

* Significant. T1 = Control, T2 = RFD (Recommended Fertilizer Dose: N150 P40 K100 S15 Zn2.5 kg/ha, T3 = RFD + Biochar @ 1 ton/ha, T4 = RFD + Biochar @ 1.5 ton/ha, T5 = RFD + Biochar @ 2 ton/ha, T6 = ⅔ RFD + Biochar @ 1 ton/ha, T7 = ⅔ RFD + Biochar @ 1.5 ton/ha, T8 = ½ RFD + Biochar @ 2 ton/ha.

4. Discussion

4.1. Crop Growth, Yield, and Yield Components

Salts that have been dissolved in the soil solution are close to the plant roots and have the potential to inhibit plant growth. This is because the osmotic effect causes a reduction in the amount of water that plants can take in, which in turn lowers the water potential of the plant's leaves and tissues. An excessive concentration of salts within the plant's tissues will negatively impact the plant's growth and productivity because salts can interfere with several critical processes, including germination, photosynthesis, nutrient balance, and redox balance, among others. This will cause the plant to be unable to reach its full potential [39].

Biochar has been shown to immobilize sodium ions, limiting their uptake by plant roots [40]. Our research showed that increasing the amount of biochar to 2 tons per hectare effectively reverses the fruit-yield loss caused by salinity and decreases the amount of sodium accumulated in the roots and fruit. The amount of sodium in wheat grains grown in low-fertile soil impacted by salinity in the Yellow River Delta was recently reported to be reduced by adding biochar at 12 tons per hectare (Xiao et al., 2022) [41]. A greater quantity of biochar applied to a tomato plant might improve its adaptive response to saline water by reducing sodium uptake into plant tissue [42], but this was not investigated in this work. This theory was never put to the test, though. However, extreme caution is warranted when incorporating biochar into clay soil because an unoptimized high addition could disrupt the equilibrium between the liquid and gaseous phases, decreasing the readily available water in the rhizosphere [43].

As a result, we hypothesize that biochar's salinity-stress-mitigating-effect (double stressor environmental stress imposes both physiological drought and sodium ion toxicity) needs to be fine-tuned through extensive comparative studies to be optimally effective. According to the findings of our study, the addition of biochar to saline soil had the potential to improve the growth of some vegetative growth characteristics (Table 3), but it did not mitigate the detrimental effect of salt stress on tomato fruit yield. Compared with the control, tomato height, the number of fruits produced, and yield significantly improved when biochar was applied at a rate of T5 = RFD plus 2 tons of biochar per hectare. Additionally, it was observed that the height of the tomato plants, the yield, and the number of fruits produced increased in direct proportion to the amount of biochar that was applied. The control with T1 = Control had the lowest tomato height, measured at 46.37 cm, and T5 recorded the highest value (65.38 cm). According to our research findings, the application of biochar made from wood charcoal acts as a buffering agent for soil quality. This, in turn, leads to an increase in plant growth parameters as well as an increase in yield.

Compared with the control, the application of biochar treatments on the plot significantly influenced the grading of tomato fruits measured as a percentage of the total number of fruits. As a result of our observations of this experiment, we can deduce that the T5 treatments resulted in exceptionally high fruit-quality tomatoes. This observation is most likely due to the use of biochar, which significantly reduced the number of pest and disease attacks in the field compared with the control. Using biochar before transplanting seedlings helped to mobilize the soil properties and increase soil productivity by ensuring that the soil remained in good health. The use of wood charcoal or biochar in powder form has been shown to increase the grading of tomatoes, leading to an increase in the market value of tomatoes. This is achieved by using a soil buffering agent, i.e., biochar.

4.2. Characterization of Biochar on Soil's Physical and Chemical Properties in Post-Harvest Soil

In most cases, bulk density is evaluated on a routine basis to characterize the state of the soil's compactness as a reaction to various land management practices and land uses. The bulk density of the soil reflects the quantity or weight of an amount of soil contained in a certain volume. The infiltration rate, available water capacity, soil porosity, rooting depth or restrictions, soil microorganism activity, root proliferation, and availability of nutrients are primarily determined by the bulk density of the soil. When the bulk density of a material rises, the number of macropores in the material will fall, while the number of macropores and micropores will rise. These changes will affect the hydraulic conductivity of the material.

In tomato cultivation, the post-harvest bulk density of saline soil was found to vary depending on the biochar application levels used in conjunction with RFD. However, we can see that using biochar with RFD can decrease the soil's organic carbon and the bulk density of saline soil. This is because increasing the bulk density of soil leads to an increase in soil compaction, reducing the plant's ability to extract nutrients from the soil. The bulk density of post-harvest soil was a maximum of 1.63 in the treatment T1, which did not receive any fertilizers or biochar. The post-harvest saline soil with the lowest bulk density was found in a treatment known as T5 (T5 = RFD + Biochar @ 2 tons/ha), which did not receive any biochar or RFD. This resulted in a value of 1.037. The bulk density has an impact on the pore diameter as well as its distribution, which in turn has an effect on the hydraulic properties of the soil [44,45].

According to research by (Dec et al., 2008) [44], an increase in bulk density not only brings about shifts in the pore-size distribution but also affects the soil's capacity to contract and move water throughout the soil. Aside from this, several researchers discovered a significant and inverse correlation between the bulk density of soil and its organic matter content [46]. However, these relationships change depending on the type of soil and the depth of the soil [47]. The reduction in organic carbon was correlated with an increase in the bulk density of the soil. The loss of organic carbon as a result of increased decomposition as a result of elevated temperature [48] may lead to an increase in bulk density and, as a result, make the soil more prone to compaction as a result of land management activities and climate change stresses from variable and high-intensity rainfall and drought events [48,49]. It is likely that the rooting depth will have an effect on the plant's available water capacity, subsoil salinity, soil organic carbon content, or any of the other properties that indicate major constraints in the soil profile [49].

The ratio of the mass of a particular quantity of an aggregate to the volume of all of the individual particles that make up that quantity is what is meant to be understood as the particle density of the aggregate. This volume takes into account the voids that are present within the particles themselves but does not take into account the space that exists between the particles. The specific density of the material and the particles' void content both affect the particle density, which is a function of both of these factors. The amount of empty space within the particles is the primary factor determining their density [50]. Due to the application of biochar and the recommended dose of fertilizers, the particle density of soil in salty areas can vary. Controlled treatment is the gold standard. Compared with control treatment T1, the post-harvest soil's particle density was 1.08 times lower than in the T5 treatment (where T5 = RFD + biochar @ 2 tons/ha). The T1 treatment produced post-harvest soil with a particle density (Pd) 2.65 times higher than any other treatment. In some instances, the lowest particle density was also observed in the treatment known as "T8 = 12 RFD + Biochar @ 2 tons/ha." This treatment involved using half biochar in conjunction with the recommended dose of fertilizers, which decreased the particle density of the saline soil. This proved to be very helpful for crop production in areas where salinity was a problem.

When we use biochar in conjunction with RFD, we can reduce the soil's bulk density and particle density while simultaneously increasing the porosity of the soil. This results in an increase in the water and nutrient-holding capacity of saline soil, which in turn results in an increase in the yield of salinity-affected areas in saline soils. Porosity in saline soils varies by 48.65 inches compared with control treatment T1 (T5 = RFD + biochar @ 2 tons/ha). The lowest porosity of soil varies depending on the standard control and the simple application of the recommended fertilizers in salty environments. According to Oliverla et al. (1996) [51], it is common knowledge that temperature changes result in changes in humidity, resulting in a liquid flow towards the hot source and a vapor flow away from the hot source. When this phenomenon occurs in saline media, the liquid present is a salt-saturated brine; consequently, evaporation causes salt precipitation, which in turn leads to a reduction in porosity. Condensation of water causes salt to dissolve and porosity to rise. This process may be significant in the case of waste that generates heat because it provides evidence that self-sealing may occur near the waste. On the other hand, the salt mass balance will cause increases in porosity in other zones.

One of the coastal areas in Bangladesh that are severely impacted by salinity is located in the Doulatpur region of Khulna, home to Khulna Agricultural University. This study was carried out to determine the level of soil salinity (EC value) and to compare the collected data with the data that SRDI obtained in 2022 from comparable locations. The sampling sites subjected to biochar application with RFD were discovered to have a lower electrical conductivity value. In contrast, the sampling sites that had been subjected to rice cultivation showed an increase in EC value. The pH and electrical conductivity of soil are considered to be master variables in soils because they control a large number of chemical and biochemical processes taking place within the soil. It is a measurement that determines whether the soil is acidic or alkaline. The study of soil pH and electrical conductivity is very important in agriculture because soil pH regulates plant nutrient availability. This occurs because soil pH controls the chemical forms of the various nutrients and also influences the chemical reactions that occur between those nutrients. The productivity of the soil and the productivity of the crops are thus correlated with the pH and EC values of the soil. The sweet spot for most crops is between 5.5 and 7.5, despite the fact that the pH of the soil can vary from 1 to 14.

Some plant species have evolved to survive and even thrive in soils with pH levels outside this optimum range. The United States Department of Agriculture's National Resources Conservation Service has a four-tiered system for describing soil acidity: ultra-acidic (9.0) [52]. The soil's pH and electrical conductivity are affected by the parent material's mineral makeup and the material's weathering reactions. Soil acidification is caused, for example, by weathering products leached by water moving laterally or downwards through the soil for a long time [53]. In dry environments, soil weathering and leaching are less intense, and the soil pH is typically neutral or alkaline. Due to greater shrimp cultivation in the sampling sites, the soil pH and soil EC values tend to be the highest.

When the soil pH value is high, also known as having saline soil, the soil EC value will also be high, which indicates an increase in soil salinity. Compared with the control treatment, the experimental post-harvest soils demonstrated that biochar application alongside recommended fertilizers neutralized the soil pH and lowered the soil EC value. The neutral soil pH of 6.51 was discovered in the T5 treatment (T5 = RFD + Biochar @ 2 tons/ha), which received biochar in addition to RFD, and in some instances, also found a neutral pH after treatment with T7 = RFD + biochar @ 1.5 tons/ha. The T5 treatment, which was biochar together with RFD (at a rate of 2 tons per hectare), had the lowest EC value, while the control treatment had the highest value. Therefore, these kinds of soil have the highest pH and EC values, which raise the soil salinity by 0.6 ppt. This was discovered in control treatment T1, which did not receive any biochar use. However, the biochar treatment showed the lowest salinity value of 0.1 ppt in areas where the EC value was 100 µS/cm.

4.3. Biochar with RFD on Saline Soil Organic Matter, Organic Carbon (OC), and Nutrient Availability

Organic matter in the soil influences soil health, microbial activity, nutrient cycling, and water retention (SOM). Soil biochar has been shown to increase its C content, its ability to retain water, and the strength of aggregates. The P sorption capacity is highly dependent on the feedstock type and the temperature of pyrolysis, which in turn affects some of the most important physicochemical properties of biochar (structural characteristics, electrical conductivity (EC), mineral composition, pH, zeta potential, cation exchange capacity (CEC), and anion exchange capacity (AEC) [54]. Responses vary widely depending on factors such as the type of feedstock used, pyrolysis conditions, application rates, and soil types in experimental fields where biochar was used. In the field, greenhouse, and laboratory treatments with manure amendments, Gross A. and coworkers (2021) [55] showed that a low initial SOC content of less than 10 g kg^{-1} resulted in a high relative SOC increase. This result contradicts those of studies involving manure amendments [56] and demonstrates that SOC stocks can be increased through biochar application regardless of the level of SOC already present. In SOC-rich soils (>20 g/kg), the increase in SOC was the highest, both in relative and absolute terms.

The most significant difficulties that soil with a low organic matter (OM) content presents are reduced nutrient availability and increased biological activity. The purpose of the current study was to evaluate the responses of soil nutrient status and biological traits to the addition of crop residue biochar produced at different pyrolysis temperatures in salty soil. This evaluation was performed with the intention of better understanding how crop residue biochar affects the soil. The pyrolysis process produces biochar, which contains trace amounts of aromatic carbon and the essential nutrients nitrogen, phosphorus, potassium, magnesium, and sulfur [57]. Since biochar improves the properties of the soil, such as CEC and surface oxidation, it increases the amount of plant nutrients available to the plant and the amount retained in the soil [58].

The availability of phosphorus (P) decreases as the pH of saline soil increases; however, applying biochar raises the availability of P by neutralizing the saline soil. Therefore, the uptake of phosphorus is increased in salty soils. However, earlier studies have shown that biochar can change the amount of phosphorus that is available in the soil in a few different ways: (a) it can serve as a source of phosphorus on its own; (b) it can change the solubility of phosphorus in the soil by affecting the pH; (c) it can change the adsorption and desorption of certain chelates; and (d) it can promote the growth of bacteria that break down phosphorus [59]. As a result, biochar is quickly becoming recognized as a viable method that can effectively cut down on synthetic fertilizers and raise NUE levels. Similarly, Adekiya et al. (2020) [60] found that biochar-amended soils had higher nitrogen, phosphorus, potassium, magnesium, and calcium concentrations than soils not amended with biochar. Biochar enhanced the growth of maize as well as the mineral content of the shoots and roots (including P, K, Ca, Na, Mg, Fe, Mn, and Zn) [31].

Bangladesh is a country that is expanding and developing at a rapid rate. This progression relies on a system of agricultural production, which brings economic visibility throughout the world. The salinity issues impede both agricultural and economic development. The methods that have been developed will assist growers in obtaining the financial benefits of high tomato yields. In addition, the yield of tomatoes in our country will be increased by a sizeable amount, which will make a significant contribution toward meeting the anticipated demand for vegetables in the future. Biochar is a useful soil amendment that can improve the properties of salty soils and facilitate the production of sustainably grown crops in various agroecological conditions. Co-application of biochar and inorganic fertilizers in saline soils have improved tomato crop growth and yield by promoting more efficient nutrient management and utilization. This can be achieved by minimizing the amount of salt in the soil. This study aimed to provide tomato growers, researchers, and policymakers in Bangladesh with specific information about tomato production in salinity conditions.

5. Conclusions

Several agronomic characteristics, such as plant height, fruit set, and yield, were positively affected by the inclusion of biochar at a rate of RFD + 2 tons/ha. Biochar applications had a sizeable impact on the chosen soil properties. Soil bulk density, soil porosity, EC, pH, and salinity significantly changed after biochar application, regardless of the treatment rate. Significant differences in soil particle density between the biochar treatments and the control group were found. Biochar applications also significantly impacted the soils' clay, sand, and silt fractions. Soil nutrient availability was found to statistically vary significantly between the two time periods studied. All biochar treatments resulted in lower pH and EC in the soil. Biochar treatments resulted in a notable increase in organic carbon and organic matter. We found that biochar has a significant capacity to improve and maintain the soil's physical and chemical properties in saline soils through the use of an approach based on data analysis. The potential for carbon sequestration was significantly different between treatments carried out in the field, in biochar, and on RFD, with RFD eliciting lower responses. According to the results of our research, biochar was most effective at storing carbon when the soil had an alkaline pH, a higher amount of biologically based manure, plant residues as biochar feedstock, a finer soil texture, and more tomatoes were grown.

Author Contributions: Conceptualization, M.Z., K.S., and A.K.P.; methodology, M.Z., K.S., and A.K.P.; software, K.S., A.K.P., and M.Z.; validation, D.M., M.Z., and R.A.C.; formal analysis, A.K.P., M.Z., and K.S.; investigation, A.K.P., M.F.-E.-A., D.M., and M.Z.; resources, M.Z., K.S., M.F.-E.-A., and R.A.C.; data curation, A.K.P., M.F.-E.-A., M.Z., and R.A.C.; writing—original draft preparation, M.Z. and A.K.P.; writing—review and editing, A.K.P., K.S., R.A.C., and M.Z.; visualization, M.Z., M.F.-E.-A., R.A.C., and D.M.; supervision, D.M. and R.A.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to take this opportunity to express their heartfelt gratitude to the Ministry of Science and Technology, Bangladesh Secretariat in Dhaka, for their outstanding role in providing the Technology Innovation, Research and Development Grant (R&D) 2021–2022, which enabled them to conduct this research in Khulna Agricultural University's farmer fields.

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

References

1. Dasgupta, S.; Hossain, M.; Huq, M.; Wheeler, D. Climate Change, Salinization and High-Yield Rice Production in Coastal Bangladesh. *Agric. Resour. Econ. Rev.* **2018**, *47*, 66–89. [CrossRef]
2. Agrawala, S.; Ota, T.; Ahmed, A.U.; Smith, J.; Aalst, M.V. *Development and Climate Change in Bangladesh: Focus on Coastal Flooding and the Sunderbans*; Organization for Economic Co-Operation and Development (OECD): Paris, France, 2003.
3. Hasan, M.H.; Rahman, M.R.; Haque, A.; Hossain, T. Soil salinity hazard assessment in Bangladesh coastal zone. In Proceedings of the International Conference on Disaster Risk Management, Dhaka, Bangladesh, 12–14 January 2019.
4. Alam, M.Z.; Carpenter-Boggs, L.; Mitra, S.; Haque, M.; Halsey, J.; Rokonuzzaman, M.; Saha, B.; Moniruzzaman, M. Effect of salinity intrusion on food crops, livestock, and fish species at Kalapara Coastal Belt in Bangladesh. *J. Food Qual.* **2017**, *2017*, 2045157. [CrossRef]
5. Haque, S.A. Salinity problems and crop production in coastal regions of Bangladesh. *Pak. J. Bot.* **2006**, *38*, 1359–1365.
6. Karim, Z.; Hussain, S.G.; Ahmed, M. *Salinity Problems and Crop Intensification in the Coastal Regions of Bangladesh*; Soils Publication No. 33; BARC: Dhaka, Bangladesh, 1990; Volume 17.
7. Karim, Z.; Saheed, S.M.; Salauddin, A.B.M.; Alam, M.K.; Huq, A. *Coastal Saline Soils and Their Management in Bangladesh*; Soils Publication No. 8; BARC: Dhaka, Bangladesh, 1982; Volume 33.
8. Das, R.S.; Rahman, M.; Sufian, N.P.; Rahman, S.M.A.; Siddique, M.A.M. Assessment of soil salinity in the accreted and non-accreted land and its implication on the agricultural aspects of the Noakhali coastal region, Bangladesh. *Heliyon* **2020**, *6*, e04926. [CrossRef]
9. Cuevas, J.; Daliakopoulos, I.N.; del Moral, F.; Hueso, J.J.; Tsanis, I.K. A Review of Soil-Improving Cropping Systems for Soil Salinization. *Agronomy* **2019**, *9*, 295. [CrossRef]
10. Lehmann, J.; Stephen, J. Biochar effect on soil hydrology. In *Biochar for Environmental Management: Science, Technology and Implementation*; Rountledge; Taylor & Francis Group: London, UK, 2015; pp. 543–563.
11. Shackley, S.; Ruysschaert, G.; Zwart, K.; Glaser, B. *Biochar in European Soils and Agriculture*; Rountledge; Taylor & Francis Group: New York, NY, USA, 2016.
12. Manisankar, G. Potential Impact of Biochar in Agriculture: A Review Potential Impact of Biochar in Agriculture: A Review. *Int. J. Agric. Sci.* **2022**, *13*, 466–475.
13. Baskar, G.; Kalavathy, G.; Aiswarya, R.; Abarnaebenezer Selvakumari, I. Advances in bio-oil extraction from nonedible oil seeds and algal biomass. In *Advances in Eco-Fuels for a Sustainable Environment, a Volume in Woodhead Publishing Series in Energy*; Azad, K., Ed.; Woodhead Publishing: Soston, UK, 2019; pp. 187–210.
14. Mensah, A.K.; Frimpong, K.A. Biochar and/or Compost Applications Improve Soil Properties, Growth, and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana. *Int. J. Agron.* **2018**, *2018*, 6837404. [CrossRef]
15. Liu, X.; Feng, P.; Zhang, X. Effect of biochar on soil aggregates in the Loess Plateau: Results from incubation experiments. *Int. J. Agric. Biol.* **2012**, *14*, 975–979.
16. Zhao, X.; Hu, M. Capillary forces between particles: Role of biochar in improving water retention capacity of soil. *Arab. J. Geosci.* **2021**, *14*, 1769. [CrossRef]
17. Xiao, L.; Meng, F. Evaluating the effect of biochar on salt leaching and nutrient retention of Yellow River Delta soil. *Soil Use Manag.* **2020**, *36*, 740–750. [CrossRef]
18. Apori, S.O.; Byalebeka, J.; Muli, G.K. Residual effects of corncob biochar on tropical degraded soil in central Uganda. *Environ. Syst. Res.* **2021**, *10*, 35. [CrossRef]

19. Choudhary, T.K.; Khan, K.S.; Hussain, Q.; Ashfaq, M. Nutrient availability to maize crop (*Zea mays* L.) in biochar amended alkaline subtropical soil. *J. Soil Sci. Plant Nutr.* **2021**, *21*, 1293–1306. [CrossRef]
20. Shamim, M.I.A.; Dijkstra, F.A.; Abuyusuf, M.; Hossain, A.I. Synergistic effects of biochar and NPK fertilizer on soybean yield in an alkaline soil. *Pedosphere* **2015**, *25*, 713–719.
21. Yilangai, R.M.; Manu, A.; Pineau, W.; Mailumo, S.; Okeke-Agulu, K. The effect of biochar and crop veil on growth and yield of Tomato (*Lycopersicum esculentus* Mill) in Jos, North central Nigeria. *Curr. Agric. Res. J.* **2014**, *2*, 37–42. [CrossRef]
22. Vinh, N.; Hien, N.; Anh, M.; Lehmann, J.; Joseph, S. Biochar treatment and its effects on rice and vegetable yields in mountainous areas of northern Vietnam. *Int. J. Agric. Soil Sci.* **2014**, *2*, 5–13.
23. Giuliani, M.M.; Nardella, E.; Gagliardi, A.; Gatta, G. Deficit irrigation and partial root-zone drying techniques in processing tomato cultivated under Mediterranean climate conditions. *Sustainability* **2017**, *9*, 2197. [CrossRef]
24. Schwarz, D.; Thompson, A.J.; Kläring, H.P. Guidelines to use tomato in experiments with a controlled environment. *Front. Plant Sci.* **2014**, *5*, 625. [CrossRef]
25. Wu, P.; Ata-Ul-Karim, S.T.; Singh, B.P.; Wang, H.; Wu, T.; Liu, C.; Fang, G.; Zhou, D.; Wang, Y.; Chen, W. A scientometric review of biochar research in the past 20 years (1998–2018). *Biochar* **2019**, *1*, 23–43. [CrossRef]
26. Kumar Yadav, N.; Vijay Kumar, I.; Kumar, V.; Sharma, K.; Singh Choudhary, R.; Singh Butter, T.; Singh, G.; Kumar, M.; Kumar, R. Biochar and Their Impacts on Soil Properties and Crop Productivity: A Review. *J. Pharmacogn. Phytochem.* **2018**, *7*, 49–54.
27. Gorovtsov, A.V.; Minkina, T.M.; Mandzhieva, S.S.; Perelomov, L.V.; Soja, G.; Zamulina, I.V.; Rajput, V.D.; Sushkova, S.N.; Mohan, D.; Yao, J. The mechanisms of biochar interactions with microorganisms in soil. *Environ. Geochem. Health* **2022**, *42*, 2495–2518. [CrossRef]
28. Huq, N.; Hugé, J.; Boon, E.; Gain, A.K. Climate change impacts in agricultural communities in rural areas of coastal Bangladesh: A tale of many stories. *Sustainability* **2015**, *7*, 8437–8460. [CrossRef]
29. The Bangladesh Meteorological Department (BMD). Abohawa Office (Weather Office) Is the National Meteorological Organization of Bangladesh, Working under Ministry of Defense of the Government of Bangladesh. 2022. Available online: https://www.bmd.gov.bd/ (accessed on 15 January 2023).
30. Page, A.L.; Miller, R.H.; Keeney, D.R. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. American Society of Agronomy. In *Soil Science Society of America*; 1982; Volume 1159. Available online: https://www.scirp.org/(S(vtj3fa45qm1ean45vvffcz55))/reference/ReferencesPapers.aspx?ReferenceID=1973856 (accessed on 12 December 2022).
31. Sun, J.; Jia, Q.; Li, Y.; Zhang, T.; Chen, J.; Ren, Y.; Dong, K.; Xu, S.; Shi, N.-N.; Fu, S. Effects of Arbuscular Mycorrhizal Fungi and Biochar on Growth, Nutrient Absorption, and Physiological Properties of Maize (*Zea mays* L.). *J. Fungi* **2022**, *8*, 1275. [CrossRef] [PubMed]
32. BARC. *Fertilizers Recommendation Guide*; Bangladesh. 2018. Available online: http://www.bfa-fertilizer.org/wp-content/uploads/2019/09/Fertilizer-Recommendation-Guide-2018-English.pdf (accessed on 1 October 2022).
33. Gomez, K.A.; Gomez, A.A. *Statistical Procedure for Agricultural Research*, 2nd ed.; John Wiley & Sons: Hoboken, NJ, USA, 1984; pp. 28–192.
34. R Studio Team. *R Studio: Integrated Development for R*; R Studio, Inc.: Boston, MA, USA; Available online: http://www.rstudio.com/ (accessed on 4 November 2018).
35. Karim, M.R.; Halim, M.A.; Gale, N.V.; Thomas, S.C. Biochar Effects on Soil Physiochemical Properties in Degraded Managed Ecosystems in Northeastern Bangladesh. *Soil Syst.* **2020**, *4*, 69. [CrossRef]
36. Wang, J.; Xiong, Z.; Kuzyakov, Y. Biochar stability in soil: Meta-analysis of decomposition and priming effects. *GCB Bioenergy* **2016**, *8*, 512–523. [CrossRef]
37. Koçer, A.T.; Mutlu, B.; Özçimen, D. Investigation of biochar production potential and pyrolysis kinetics characteristics of microalgal biomass. *Biomass Convers. Biorefin.* **2020**, *10*, 85–94. [CrossRef]
38. Azzi, E.S.; Karltun, E.; Sundberg, C. Small-scale biochar production on Swedish farms: A model for estimating potential, variability, and environmental performance. *J. Clean. Prod.* **2021**, *280*, 124873. [CrossRef]
39. Parihar, P.; Singh, S.; Singh, R.; Vijay Pratap Singh, V.P.; Prasad, S.M. Effect of salinity stress on plants and its tolerance strategies: A review. *Environ. Sci. Pollut. Res.* **2015**, *22*, 4056–4075. [CrossRef]
40. El-sayed, M.E.; Hazman, M.; Abd El-Rady, A.G.; Almas, L.; McFarland, M.; Shams El Din, A.; Burian, S. Biochar Reduces the Adverse Effect of Saline Water on Soil Properties and Wheat Production Profitability. *Agriculture* **2021**, *11*, 1112. [CrossRef]
41. Xiao, L.; Yuan, G.; Feng, L.; Mustafa Shah, M.; Wei, J. Biochar to Reduce Fertilizer Use and Soil Salinity for Crop Production in the Yellow River Delta. *J. Soil Sci. Plant Nutr.* **2022**, *22*, 1478–1489. [CrossRef]
42. Kul, R.; Arjumend, T.; Ek, M.; Yildirim, E.; Turan, M.; Argin, S. Role of Biochar in Mitigating Salinity Stress in Tomato. *Soil Sci. Plant Nutr.* **2020**, *11*, 59–65.
43. Castellini, M.; Giglio, L.; Niedda, M.; Palumbo, A.D.; Ventrella, D. Impact of Biochar Addition on the Physical and Hydraulic Properties of a Clay Soil. *Soil Tillage Res.* **2015**, *154*, 1–13. [CrossRef]
44. Dec, D.; Dörner, J.; Becker-Fazekas, O.; Horn, R. Effect of bulk density on hydraulic properties of homogenized and structured soils. *J. Soil Sci. Plant Nutr.* **2008**, *8*, 1–13.
45. Buczko, U.; Bens, O. Assessing soil hydrophobicity and its variability through the soil profile using two different methods. *Soil Sci. Soc. Am. J.* **2006**, *70*, 718–727. [CrossRef]

46. Sakin, E. Organic carbon organic matter and bulk density relationships in arid-semi arid soils in Southeast Anatolia region. *Afr. J. Biotechnol.* **2012**, *11*, 1373–1377.
47. Westman, C.J.; Hytönen, J.; Wall, A. Loss-on-ignition in the determination of pools of organic carbon in soils of forests and afforested arable fields. *Commun. Soil Sci. Plant Anal.* **2006**, *37*, 1059–1075. [CrossRef]
48. Davidson, E.A.; Janssens, I.A. Temperature Sensitivity of Soil Carbon Decomposition and Feedbacks to Climate Change. *Nature* **2006**, *440*, 165–173. [CrossRef] [PubMed]
49. Birkás, M.; Jolánkai, M.; Gyuricza, C.; Percze, A. Tillage effects on compaction, earthworms and other soil quality indicators in Hungary. *Soil Tillage Res.* **2004**, *78*, 185–196. [CrossRef]
50. Colangelo, F.; Cioffi, R.; Farina, I. (Eds.) *Handbook of Sustainable Concrete and Industrial Waste Management*; 2022. Available online: https://www.sciencedirect.com/book/9780128217306/handbook-of-sustainable-concrete-and-industrial-waste-management#book-info (accessed on 12 November 2022).
51. Olivella, S.; Carrera, J.; Gens, A.; Alonso, E.E. Porosity variations in saline media caused by temperature gradients coupled to multiphase flow and dissolution/precipitation. *Transp. Porous Media* **1996**, *25*, 1–25. [CrossRef]
52. Anjum, S.A.; Ashraf, U.; Zohaib, A.; Tanveer, M.; Naeem, M.; Ali, I.; Tabassum, T.; Nazir, U. Growth and developmental responses of crop plants under drought stress: A review. *Zemdirb. Agric.* **2017**, *104*, 267–276. [CrossRef]
53. Bloom, P.R.; Skyllberg, U. Soil pH and pH buffering. In *Handbook of Soil Sciences: Properties and Processes*, 2nd ed.; Huang, P.M., Li, Y., Sumner, M.E., Eds.; CRC Press: Boca Raton, FL, USA, 2012.
54. Nobaharan, K.; Bagheri Novair, S.; Asgari Lajayer, B.; van Hullebusch, E.D. Phosphorus Removal from Wastewater: The Potential Use of Biochar and the Key Controlling Factors. *Water* **2021**, *13*, 517. [CrossRef]
55. Gross, A.; Glaser, B. Meta-analysis on how manure application changes soil organic carbon storage. *Sci. Rep.* **2021**, *11*, 5516. [CrossRef] [PubMed]
56. Gross, A.; Bromm, T.; Glaser, B. Soil Organic Carbon Sequestration after Biochar Application: A Global Meta-Analysis. *Agronomy* **2021**, *11*, 2474. [CrossRef]
57. El-Naggar, A.; El-Naggar, A.H.; Shaheen, S.M.; Sarkar, B.; Chang, S.X.; Tsang, D.C.W.; Rinklebe, J.; Ok, Y.S. Biochar composition-dependent impacts on soil nutrient release, carbon mineralization, and potential environmental risk: A review. *J. Environ. Manag.* **2019**, *241*, 458–467. [CrossRef] [PubMed]
58. Karimi, A.; Moezzi, A.; Chorom, M.; Enayatizamir, N. Application of biochar changed the status of nutrients and biological activity in a calcareous soil. *J. Soil Sci. Plant Nutr.* **2020**, *20*, 450–459. [CrossRef]
59. Gao, S.; DeLuca, T.H. Influence of biochar on soil nutrient transformations, nutrient leaching, and crop yield. *Adv. Plants Agric. Res.* **2016**, *4*, 348–362.
60. Adekiya, A.O.; Agbede, T.M.; Olayanju, A.; Ejue, W.S.; Adekanye, T.A.; Adenusi, T.T.; Ayeni, J.F. Effect of biochar on soil properties, soil loss, and cocoyam yield on a tropical sandy loam Alfisol. *Sci. World J.* **2020**, *2020*, 9391630. [CrossRef]