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Effects of Different Doses of Biochar Applications on Yield and Nutrient Element Concentrations on Wheat Grown under Salt Stress

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ABSTRACT

In the study, the effects of different doses of biochar applications on the yield and nutrient uptake of wheat grown under salt stress in greenhouse conditions were investigated. The study was conducted in 2 kg capacity plastic pots with three replications using a random plot design. In the study, salt doses were applied as 0 dS m^{-1}, 6 dS m^{-1} and 12 dS m^{-1} (in the form of NaCl), and biochar doses (BC) were applied as 0%, 0.5%, 1% and 2% W/W. At the end of the study, the dry matter yield of wheat plant and sodium (Na), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), zinc (Zn), manganese (Mn), iron (Fe) and copper (Cu) concentrations were determined. Study results showed that BC applications increased the dry matter production of the plant, and the highest was obtained with 2% BC application at 6 6 dS m^{-1} salt dose, 1.85 g pot^{-1}. However, due to increasing salt doses, BC applications had no effect on the phosphorus and potassium concentrations of the wheat plant, except for calcium, and decreases were determined in the average values. In the study, although all BC applications increased iron, zinc, manganese and copper concentrations compared to the control, when evaluated in terms of average values, decreases were detected in the microelement concentrations of the plant due to increasing salt doses.

Keywords: Abiotic stress, Biochar soil conditioner, Salinity mitigation, Wheat crop resilience, Enhanced nutrient availability.

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Introduction

The salinity problem in agricultural production areas leads to soil degradation on one hand and yield losses in plant production on the other. Saline soils are generally found predominantly in arid and semi-arid regions. The use of low quality irrigation water in agricultural areas, inappropriate irrigation methods and inadequate drainage conditions cause the salinity problem to increase day by day. It has been reported that the electrical conductivity of saline soils is higher than 4 mmhos / cm and the percentage of exchangeable sodium (Na) is less than 15 [1]. In general, it is known that the dominant salt form in soils is NaCl and that the highest crop yield losses are caused by this salt. More than 800 million hectares of land worldwide face both salinity and alkalinity problems [2]. In Türkiye, it has been reported that there is a salinity problem in an area of 1.5 million hectares [3]. There may be significant changes in the morphology of plants grown under salt stress. Accordingly, salinity retards the growth of plants, causing leaf appearance to be small and dull bluish-green, and shoot growth generally declines more than root growth [4]. It has been reported that the first symptoms of salinity-related toxicity in plants growing in saline areas are chlorosis, which starts from the tips of old leaves and progresses to the leaf blade and stem, and then turns into necrosis [5].

Biochar is produced by heating plant biomass in the absence of oxygen and is a relatively new term that has emerged in relation to issues of soil management and carbon (C) enrichment [6]. The production and application of biochar to the soil is a new process in order to limit the risk of CO_2 return in the atmosphere and reduce the CO_2 storage in the long term [6]. Carbon-rich materials obtained by heating various biomass such as wood, animal manure and leaves in a closed environment where there is little or no oxygen are called biochar. In a more technical sense, the material produced by the exchange/pyrolysis of organic materials in the presence of a limited amount of oxygen and at relatively low temperatures (<700 °C) is called biochar [7]. It is an important issue to investigate this valuable product called biochar in terms of different application areas due to its high surface area and porous structure, especially in improving soil quality and removing pollution [8]. Due to the recalcitrant nature of biochar (obtained from charcoal or biomass) in reducing greenhouse gas emissions, there has been growing interest in its use as a soil amendment [9]. Recently, studies on biochar have increasingly focused on its effectiveness in enhancing both the sustainability and productivity of agricultural systems [10-11]. In this study, the effects of different doses of biochar obtained from peanut shells on the yield and nutrient uptake of Kızıltan wheat variety grown under salt stress in greenhouse conditions were investigated.

Material and Methods

The greenhouse experiment was carried out in the greenhouses of Erciyes University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition. The experiment was set up according to the random parcel design with three repetitions. The soil used in the experiment; It has a clay loam texture and slightly alkaline pH (7.98), low organic matter content (1.77%), salt-free (0.02%), medium calcareous (9.95%), low phosphorus concentration (56.8 kg P_2O_5 ha^{-1}) and low potassium concentration (987.1 kg K_2O ha^{-1}). Plastic pots were used in the experiment and 3000 g of soil was placed in each pot. In the experiment, as basic fertilization, 200 mg N kg^{-1} (in the form of $CaNO_3.4H_2O$), 100 mg P kg^{-1} and 125 mg K kg^{-1} (in the form of KH_2PO_4), 2.5 mg Zn kg^{-1} (in the form of $ZnSO_4.7H_2O$) and 2.5 mg Fe kg^{-1} (in the form of Fe-EDTA) was applied to each pot. In the experiment, salt concentrations were applied using a NaCl source at 0 dS m^{-1}, 6 dS m^{-1} and 12 dS m^{-1} levels. 1/3 of each salt dose was initially mixed into the soil, and the remaining part was completed with irrigation water along with the outlets. Pure water was used for irrigation and care was taken to avoid water loss from the bottom of the pot. The Kızıltan wheat variety was utilized as the plant material. Initially, 12 wheat seeds were sown in each pot, and after germination, the seedlings were thinned to reduce the number to 8.

In the study, biochar obtained from peanut shells by slow pyrolysis and burning at 400 ^{0}C for 2 hours was applied as 0%, 0.5%, 1% and 2% w/w. Approximately 50 days after planting, the harvested plants were brought to the laboratory and washed first with tap water, then with 0.1% N HCl, and then with pure water. The plant leaves, placed separately in a paper bag, were dried in an air circulation drying cabinet at 70 ^{0}C until they reached a constant weight. The samples, whose dry weights were determined, were ground in a plant grinding mill. 0.2 g of ground plant samples were weighed and burned in an acid mixture of H_2O_2-HNO_3 (2 ml of 35% H_2O_2 and 5 ml of 65% HNO_3) according to the wet combustion method in a microwave device, and the final volume was completed to 20 mL with pure water and filtered through blue band filter paper. From the obtained filters, phosphorus (P) concentration was measured colorimetrically in a spectrophotometer at 882 nm [12], potassium (K), calcium (Ca), sodium (Na), zinc (Zn), manganese (Mn), iron (Fe) and copper (Cu) concentrations were determined by Atomic Absorption Spectrophotometer device (Shimadzu AA-7000) [13]. Nitrogen (N) determination was made according to the Kjeldahl distillation method [14]. Research findings and all measured variables were analyzed using the SPSS 20.0 for Windows package program for statistical analysis, and the differences between the means were determined with the Tukey test at a significance level of $p < 0.05$.

Results and Discussion

In the study, the dry matter production and Na concentration of the wheat plant are given in Table 1, the N and P concentrations are given in Table 2, the K and Ca concentrations are given in Table 3, the Fe and Zn concentrations are given in Table 4, and the Mn and Cu concentrations are given in Table 5.

Table 1. Effects of the applications on the dry matter production (g pot^{-1}) and Na concentration of the wheat plant (%)

Applications		Dry Matter Production (g pot^{-1})		Na (%)	
0 dS m^{-1}	0% BC	1.23	±0.01 ef	1.68	±0.35 g
	0.5 % BC	1.61	±0.06 bc	2.28	±0.02 fg
	1% BC	1.73	±0.04 ab	2.66	±0.16 fg
	2% BC	1.73	±0.08 ab	3.55	±0.60 f
Average		1.57		2.54	
6 dS m^{-1}	0% BC	1.24	±0.20 ef	14.05	±0.70 e
	0.5 % BC	1.42	±0.02 d	16.62	±0.32 c
	1% BC	1.48	±0.01 cd	16.12	±1.19 cd
	2% BC	1.85	±0.06 a	14.50	±1.87 de
Average		1.50		15.32	
12 dS m^{-1}	0% BC	1.18	±0.04 e-g	27.56	±0.05 a
	0.5 % BC	1.14	±0.03 fg	27.09	±0.05 a
	1% BC	1.33	±0.02 de	24.67	±1.58 b
	2% BC	1.06	±0.11 g	25.86	±0.59 ab
Average		1.18		26.29	

P<0.05

When Table 1 is evaluated in terms of the effects of the applications on the dry matter production of the wheat plant in the research, the highest dry matter production was obtained with 1.85 g pot^{-1} in 2% BC application at 6 dS m^{-1} salt dose. This application was followed by 1% BC and 2% BC applications at 0 dS m^{-1} salt dose, production at 1.73 g pot^{-1}. The lowest dry matter production was determined at 1.06 g pot^{-1} and 2% BC application at a salt dose of 12 dS m^{-1}. Research results show that when moderate salt is applied, 2% BC application significantly increases the dry matter production of the plant compared to the control. In addition, BC applications at all three salt doses generally increased the dry matter production of wheat plants compared to the control. In a similar study, [15] conducted a study to evaluate the potential of biochar and gibberellic acid (GA3) to reduce salinity stress in wheat. In this study, two different salinity levels (2.43 dS m^{-1} and 5.11 dS m^{-1}) and eight different combinations (T1-T8) were used. The combinations applied in the trial are: T1 (control with 2.43 dS m^{-1} EC), T2 (salinity stress with 5.11 dS m^{-1} EC), T3 (10 mg kg^{-1} GA3 and 2.43 dS m^{-1} EC), T4 (10 mg kg^{-1} GA3 and 5.11 dS m^{-1} EC), T5 (0.75% biochar and 2.43 dS m^{-1} EC), T6 (0.75% biochar and 5.11 dS m^{-1} EC), T7 (2.43 dS m^{-1} EC with 10 mg kg^{-1} GA3 and 0.75% biochar) and T8 (10 mg kg^{-1} GA3 and 0.75% biochar with 5.11 dS m^{-1} EC). They reported that individual and combined applications of GA3 and biochar significantly ($P<0.05$) increased plant growth in saline conditions compared to the control. When the average dry matter production was evaluated in our research, it was determined that the dry matter production of the plant decreased as the salt doses increased. While the highest average dry matter production was determined at 0 dS m^{-1} salt dose with 1.57 g pot^{-1}, the lowest average dry matter production was determined at 12 dS m^{-1} salt dose with 1.18% g pot^{-1}.

When Na concentration was examined in the study, the highest sodium concentration was found in 0% BC application at 12 dS m^{-1} salt dose with 27.56% Na. When average Na concentrations were evaluated, it was seen that sodium concentrations increased as salt doses increased. In parallel with this increase, the dry matter production of the wheat plant also decreased. Contrary to our research results, [16] examined the effects of biochar and selenium nanoparticles (Se-NP) on the growth and biomass production of wheat irrigated with salt water in their study. In the study, biochar was used as 5% of the soil amount in 2 kg pots, 3000 ppm NaCl was applied 20 days after wheat emergence, and 30 ppm Se-NP was added 5 days after salt application. Plants were harvested after 55 days. The results showed that plants treated with the combination of NaCl, biochar and Se-NP accumulated 50% less Na in their leaves and significantly increased ($P<0.005$) growth and yield parameters. [17] reported that roots are the first organs to encounter salinity and that the decline in root growth is greater with salt stress compared to the green parts. The decline in shoot and root growth in question is due to osmotic stress in plants due to salt stress [18], ion imbalances and regressions in carbohydrate fixation [19]. Regressions in plant growth due to salt stress have been shown in different plant species, for example, wheat [20], rice [21] and corn [22].

Table 2. Effects of the applications on N and P concentration of the wheat plant (%)

Applications		N (%)		P (%)	
0 dS m^{-1}	0% BC	4.44	±0.02 ab	0.86	±0.06 ab
	0.5 % BC	4.94	±0.02 a	0.43	±0.03 d-f
	1% BC	5.04	±0.01 a	0.47	±0.02 de
	2% BC	5.10	±0.13 a	0.19	±0.01 g
Average		4.88		0.49	
6 dS m^{-1}	0% BC	4.99	±0.15 a	0.60	±0.24 cd
	0.5 % BC	4.18	±0.00 bc	0.60	±0.00 cd
	1% BC	4.46	±0.10 ab	0.26	±0.06 fg
	2% BC	4.05	±0.19 c	0.47	±0.12 de
Average		4.42		0.48	
12 dS m^{-1}	0% BC	3.66	±0.23 d	0.93	±0.00 a
	0.5 % BC	3.58	±0.28 de	0.69	±0.09 bc
	1% BC	3.30	±0.07 e	0.39	±0.07 ef
	2% BC	3.23	±0.25 e	0.18	±0.03 g
Average		3.44		0.55	

$P<0.05$

The highest N concentration of wheat plant was determined in the application of 2% BC at a dose of 5.10% N and 0 dS m^{-1} (Table 2). This application was followed by 1% BC application at 0 dS m^{-1} dose, which is statistically in the same group (5.04% N). The lowest N concentration was determined in the application of 2% BC at a dose of 12 dS m^{-1} with 3.23% N. In the study, while all BC doses at 0 dS m^{-1} salt dose increased the N concentration of the plant compared to the control, BC applications at other salt doses did not have any effect and higher N concentrations were detected in the control applications. When average N concentrations were evaluated, the N concentration of the plant decreased in parallel with increasing salt doses. Similarly, BC applications had no effect on the phosphorus concentrations of the plant. The highest P concentration was determined in 0% BC application at a dose of 12 dS m^{-1} with 0.93% P. The lowest P concentration with 0.18% P was detected in 2% BC application at the same salt dose. In all three salt doses, the P concentration of wheat plants decreased compared to the control. [23] examined the effects of biochar and P-dissolving and salt-tolerant PGPRs (Bacillus thuringiensis or Bacillus tropicus) on wheat plants. For this purpose, saline soil was added to 6 kg pots and biochar and PGPR were applied at the rate of 1% of the soil amount. Research results revealed that applications increased wheat growth and yield compared to the control group. In particular, significant improvements were achieved in the K/Na ratio, available P level and microbial biomass carbon in the soil; this led to an increase in the nutrient content (N, P, K) in roots, shoots and grains. These findings indicate that the combined use of biochar and PGPR has potential benefits in wheat cultivation in saline soil conditions.

Tablo 3. Effects of the applications on K and Ca concentration of the wheat plant (%)

Applications		K	Ca
0 dS m^{-1}	0% BC	3.51 ±0.04 c	1.07 ±0.06 e-g
	0.5 % BC	3.96 ±0.05 b	0.85 ±0.06 gh
	1% BC	4.11 ±0.02 ab	0.85 ±0.11 gh
	2% BC	4.20 ±0.01 a	0.67 ±0.01 h
	Average	3.94	**0.86**
6 dS m^{-1}	0% BC	3.12 ±0.10 de	1.28 ±0.27 de
	0.5 % BC	2.95 ±0.04 ef	1.37 ±0.00 d
	1% BC	3.10 ±0.01 de	1.27 ±0.01 d-f
	2% BC	3.45 ±0.03 c	1.02 ±0.12 fg
	Average	3.15	**1.23**
12 dS m^{-1}	0% BC	3.22 ±0.14 d	1.85 ±0.05 c
	0.5 % BC	2.82 ±0.01 f	2.51 ±0.19 a
	1% BC	2.87 ±0.04 f	2.25 ±0.21 ab
	2% BC	3.00 ±0.25 ef	2.04 ±0.03 bc
	Average	2.98	**2.16**

$P<0.05$

In the study, the K concentration of wheat plants decreased due to increasing salt doses, as did N and P concentrations (Table 3). While BC applications at 0 dS m^{-1} salt dose increased the K concentration compared to the control, BC applications at increasing salt doses were generally not effective and higher K concentrations were detected in control applications. In the study, the highest K concentration was determined in 2% BC application at 0 dS m^{-1} salt dose with 4.20% K, while the lowest was determined in 0.5% BC application at 12 dS m^{-1} salt dose with 2.82% K. When average K concentrations were evaluated, a decrease was observed due to increasing salt doses. [24] reported that excessive uptake of Na^+ ion in plants under salt stress led to less uptake of K^+ ion due to competition. Contrary to the K concentration, the calcium concentration of the plant also increased due to increasing salt doses. This situation is explained by the fact that Ca plays an important role in the selective transport of K to make the plant resistant to salinity in the presence of high Na. Consequently, under salt stress, the Ca uptake of plants increases in parallel with the sodium uptake [25-26]. Except for the 0 dS m^{-1} salt dose, all BC applications at other salt doses increased the Ca concentration of the plant compared to the control. The highest calcium concentration was determined in 0.5% BC application with 2.51% Ca and 12 dS m^{-1} salt dose, and the lowest calcium concentration was determined in 2% BC application with 0.67% Ca and 0 dS m^{-1} salt dose. [27] in their study on the use of biochar (corn stalk and rice husk) and vermicompost (VC) improves the chemical structure of the soil and the physiological and biochemical properties of plants to relieve water stress of wheat plants in saline sodic soil, VC (4% W:W), biochar (1% W:W) and VC+biochar applications were made at 50%, 75% and 100% field capacity. As a result of the study, VC-biochar combined application followed by biochar application as a single application was significantly effective on relative water content, chlorophyll content, stomatal conductance, cytotoxicity, leaf K content in relation to nutrient uptake (N, P and K), while reducing oxidative stress ($P< 0.05$) reported. Contrary to our study results, some researchers studied different plant species, such as wheat [28], sorghum [29], different pumpkin species, melon [30] and tomato [31] reported that there were decreases in Ca concentration due to salt stress. According to [32], Ca nutrition has an important role in maintaining good growth under saline conditions.

In the study, the highest Fe concentration was determined as 97.7 mg Fe kg^{-1} in 1% BC application at 0 dS m^{-1} salt dose, while the lowest was determined as 59.2 mg Fe kg^{-1} in 0% BC application at 12 dS m^{-1} salt dose (Table 4). In the study, although all BC applications at all three salt doses increased the Fe concentration of the plant compared to the control, when average Fe concentrations were examined, the Fe concentration of the plant decreased due to increasing salt doses. A similar situation applies to the Zn concentration of the plant. While Zn concentration increased with BC applications at all salt doses compared to the control, when average Zn concentrations were evaluated, decreases were detected in the Zn concentration of wheat plants due to increasing salt doses. The highest Zn concentration was detected in 2% BC application at 0 dS m^{-1} salt dose, with 147.0 mg Zn kg^{-1}. [32] investigated the determination of the effects of Zn and salt applications on the shoot parts and some element concentrations of durum wheat in a soil with Zn deficiency. In the study, 3 different Zn doses (0, 5 and 10 mg Zn kg^{-1}) were applied and 4 different salt doses (0, 0.5, 1.0 and 1.5%) were applied during the stemming period of the plants. At the end of the research, they reported that the differences in the concentration of micronutrients in the salty conditions of the durum wheat plant may be due to the decrease in water use, especially with increasing salt concentration, and the interaction resulting from the imbalance in ion uptake.

Tablo 4. Effects of the applications on Fe and Zn concentration of the wheat plant (mg kg^{-1})

Applications		Fe		Zn	
0 dS m^{-1}	0% BC	69.9	±5.37 c-e	132.3	±0.35 b-d
	0.5 % BC	86.3	±2.12 ab	137.2	±3.18 a-c
	1% BC	97.7	±2.96 a	144.1	±9.04 ab
	2% BC	76.7	±2.05 b-d	147.0	±0.42 a
Average		82.6		140.1	
6 dS m^{-1}	0% BC	64.7	±2.19 e	102.7	±8.84 fg
	0.5 % BC	66.1	±5.16 de	115.9	±5.44 ef
	1% BC	78.6	±7.85 bc	129.2	±0.07 c-e
	2% BC	76.7	±1.98 b-d	118.4	±3.96 de
Average		71.5		116.5	
12 dS m^{-1}	0% BC	59.2	±1.41 e	78.6	±0.07 h
	0.5 % BC	63.2	±2.90 e	92.0	±1.27 gh
	1% BC	70.1	±13.51 c-e	96.4	±3.25 g
	2% BC	77.0	±6.51 b-d	94.2	±16.97 g
Average		67.4		90.3	

$P<0.05$

Tablo 5. Effects of the applications on Mn and Cu concentration of the wheat plant (mg kg^{-1})

Applications		Mn		Cu	
0 dS m^{-1}	0% BC	101.5	±2.19 de	13.8	±0.42 ab
	0.5 % BC	103.4	±0.21 cd	13.3	±0.07 a-d
	1% BC	143.4	±5.23 a	14.7	±1.63 a
	2% BC	114.6	±1.34 b	13.1	±0.00 b-e
Average		115.7		13.7	
6 dS m^{-1}	0% BC	110.7	±3.75 bc	12.1	±1.06 d-g
	0.5 % BC	116.7	±2.62 b	11.7	±0.14 e-g
	1% BC	141.2	±0.64 a	12.4	±0.35 c-g
	2% BC	136.9	±6.01 a	12.5	±0.57 b-f
Average		126.3		12.2	
12 dS m^{-1}	0% BC	81.2	±0.78 f	11.1	±0.35 g
	0.5 % BC	95.4	±2.47 e	7.3	±0.92 h
	1% BC	101.3	±2.40 de	11.1	±0.28 fg
	2% BC	99.05	±7.28 de	13.7	±0.35 a-c
Average		94.2		10.8	

$P<0.05$

In terms of Mn concentration, when Table 5 is examined, the highest concentration of 143.4 mg Mn kg^{-1} was detected in the 0 dS m^{-1} salt dose with 1% BC application. This was followed by the 6 dS m^{-1}salt dose with 1% BC and 2% BC applications, which are statistically in the same group. The lowest Mn concentration was detected in 0% BC application at a salt dose of 12 dS m^{-1} (81.2 mg Mn kg^{-1}). In the study, BC applications at all salt doses increased the Mn concentration of the plant compared to the control. When the average Mn concentrations were evaluated, the highest average Mn concentration of 126.3 mg Mn kg^{-1} was determined in the 6 dS m^{-1}application, while the lowest was determined in the 12 dS m^{-1} application with 94.2 mg Mn kg^{-1}. In the study, it was seen that BC applications generally had no effect on the Cu concentration of the plant. BC applications at all salt doses did not provide a significant increase compared to the control. However, when average Cu concentrations were evaluated, it was determined that Cu concentrations decreased in parallel with increasing salt doses. In various studies, some researchers have reported that the general effect of salt stress on plants is the toxic effect of ions such as Na and Cl. This toxicity, especially in the later stages of plant development, leads to a decrease in or toxicity of nutrient uptake and transport [33-34]. As a result of this effect, the yield and quality of the plant are adversely affected [35-36].

Conclusions

In the study, which aimed to determine the effects of applying different doses of biochar obtained from peanut shells to wheat grown under salt stress in greenhouse conditions on yield and nutrient uptake, it was found that dry matter production increased with biochar applications at all salt doses, but when examined in terms of average values, dry matter production decreased with increasing salt doses. In the study, BC applications significantly increased the N concentration of the plant at the control dose of 0 dS m^{-1}, however, BC applications were not effective at increasing salt doses and control applications had higher N concentrations. BC applications had no effect on the P and K concentrations of the wheat plant, except for Ca, due to increasing salt doses, and decreases were determined in the average values. In the study, when the effects of BC applications at increasing salt doses were evaluated on the microelement concentrations of the wheat plant, although all BC applications increased Fe, Zn, Mn and Cu concentrations compared to the control, when evaluated in terms of average values, decreases were detected in the microelement concentrations of the plant due to increasing salt doses.

When the research results were evaluated as a whole, it was found that while biochar (BC) applications alone had an impact on the growth and development of the plant, the effect of BC applications on the growth and development of the wheat plant was limited when salt applications were made.

Conflict of Interest

The authors declare no conflict of interest.

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