

Chapter 3

The Impact of Biochar Applications on Specific Soil Fertility Parameters

Mahamane Galadima Moustapha and Erdem Yilmaz

Abstract

Biochar technology is a rapidly growing field of interest within the scientific community due to its multifunctional functions. This study aims to assess the impact of the application of different types of biochar on specific soil fertility parameters. To conduct this study, four different types of plant residues (Vine (*Vitis vinifera* L.), Tomato (*Solanum lycopersicum* L.), Banana (*Musa*), and Carnation (*Dianthus caryophyllus* L.)) were used to produce biochar through slow pyrolysis system at 300°C and 500°C. The experiment was designed in randomized complete block with five replications and nine treatments. The treatments included the Control, Vineyard biochar (300°C and 500°C), Tomato biochar (300°C and 500°C), Banana biochar (300°C and 500°C), and Carnation biochar (300°C and 500°C). The trial consisted of a total of 45 pots. Each pot contained 10 kg of soil and 80 g of biochar (equivalent to 20 tons ha⁻¹) strongly mixed and incubated for 300 days. At the end of the incubation period, the biochar treatments were found to improve specific soil fertility parameters (pH, EC, CEC, soil penetration resistance, and bulk density) compared to the control. The use of biochar as a soil enhancer proved to be an effective method for managing soil fertility. This research provides valuable insights into the potential benefits of biochar in sustainable agriculture.

Keywords: biochar, soil fertility, sustainable agriculture, agricultural residues management, agroecology

1. Introduction

The decline in fertility of agricultural land is primarily caused by a reduction in soil organic matter, excessive use of chemicals for nutrition and plant protection, and inadequate soil cultivation practices [1]. However, approximately 33% of agricultural land is estimated to be degraded due to erosion, salinization, compaction, acidification, and other chemical pollution factors [1]. To ensure the preservation and sustainable enhancement of soil fertility, it is crucial to implement innovative technologies for managing fertilization in a sustainable manner. Among these technologies, biochar has gained significant attention and sparked scientific debates. In the field of agriculture, biochar is utilized as soil enhancer to improve soil fertility parameters and boost crop productivity [2–9]. However, the impact of biochar application can vary significantly due to its intrinsic properties, which are heavily influenced by the type of biomass used and pyrolysis conditions [10–13]. Therefore, the aim of this

study is to assess the effectiveness of applying different types of biochar produced from various crop residues, pyrolyzed at two different temperatures rate (300°C and 500°C) on specific soil fertility parameters.

By evaluating the impact of these different biochar applications on soil fertility, we can gain valuable insights into their potential as sustainable fertilization management tools. This research will contribute to the development of more effective strategies for maintaining and enhancing soil fertility, ultimately benefiting agricultural practices and ensuring long-term sustainability.

2. Materials and methods

2.1 Location and characteristics of the experiment site

The research was carried out in a modern greenhouse located in Mediterranean climate zone of Akdeniz University, Antalya, Türkiye. The soil of this region belongs to Xerofluvent taxonomic class; summers are hot and dry; winters are warm and rainy. The annual average temperature is around 16.3°C, whereas the average annual precipitation is 725.9 mm, and most of the precipitation occurs in winter. The average of relative humidity is 63.2%.

2.2 Original soil collection and characteristics

The experimental soil was collected from the soil surface (0–20 cm) of Aksu field, located in the Agriculture Research and Application of Akdeniz University and analyzed in the laboratories of soil science and plant nutrition department of Agricultural Faculty of Akdeniz University of Antalya, Türkiye. The original soil had texture of clay loam soil and was composed of 10.88% sand, 42.4% silt, and 46.72% clay. Soil characterization results are presented in **Table 1**.

2.3 Biochar characteristics

Four different agricultural residues were used to produce biochar used in this study; it included Vineyard (VB), Tomatoes (TB), Banana (BB), and Carnation (CB). The biochar was produced by slow pyrolysis system at 300°C and 500°C for 12 h. Prior to use, the biochar were ground into a small particle size of less than 1 mm using a sieve. A sample of the biochar was taken for characterization. The following analysis were performed in order to figure out the characteristics of the biochar. Proximate analysis was performed following ASTM D3173-03, ASTM D3175-07, and ASTM D3174-02 methods for moisture, volatile matter, and ash, respectively. Fixed carbon content was determined by difference (ASTM D3172-07a). Elemental analysis was performed using the Elemental Analyzer (CHNS-932 LECO). pH 1:10 biochar:water ratio was used to determine the pH and EC [14]. The basic physical and chemical properties of pyrolyzed biochar are shown in **Table 2**.

2.4 Experimental design

The trial was designed in a factorial randomized complete block with nine treatments and five replications. The treatments consisted of biochar obtained from various residues pyrolyzed at 300°C and 500°C. They included Vineyard biochar

Soil properties	Results
pH (1:2.5)	7.7
EC dS m ⁻¹ (1:2.5)	1.96
Lime (CaCO ₃) (%)	29.8
Sand (%)	10.88
Clay (%)	46.72
Silt (%)	42.40
Organic matter (%)	1.94
Total nitrogen (%)	0.119
Available P (kg P ₂ O ₅ da ⁻¹)	2.62
Extractable K (kg K ₂ O da ⁻¹)	35.0
Extractable Ca (kg CaO da ⁻¹)	1407.4
Extractable Mg (kg MgO da ⁻¹)	74.4
Available Fe (ppm)	795
Available Mn (ppm)	5.43
Available Zn (ppm)	0.12
Available Cu (ppm)	1.70

Table 1.
Physicochemical properties of the original soil.

Parameters	Treatments							
	VB300	VB500	TB300	TB500	BB300	BB500	CB300	CB500
pH (1:10)	8.13	9.19	8.92	9.67	8.72	10.01	9.56	9.82
EC (dS m ⁻¹)	0.29	0.56	4.41	4.44	3.41	3.64	4.92	6.23
C (%)	63.57	54.75	60.00	51.62	51.75	47.69	54.00	49.93
H (%)	4.53	2.62	3.77	2.29	3.97	1.92	4.55	1.88
N (%)	1.37	0.86	1.78	1.39	0.67	1.04	3.22	2.49
O (%)	30.53	41.77	34.15	44.27	43.48	49.18	38.11	45.42
FC	58.01	73.03	40.42	46.51	41.42	54.35	33.05	40.82
Ash	5.39	8.93	23.82	30.62	17.65	25.55	23.92	32.48
VM	33.26	14.01	30.87	19.86	37.13	17.38	38.66	22.55

FC: Fix Carbon; VM: Volatile Matter; VB: Vineyard Biochar; TB: Tomato Biochar; BB: Banana Biochar; CB: Carnation Biochar.

Table 2.
Physicochemical properties of biochar.

(VB300, VB500), Tomato biochar (TB300, TB500), Banana biochar (BB300, BB500), and Carnation biochar (CB300, CB500). A total of 45 pots (four different types of agricultural residues × two pyrolysis temperature × five replications + five controls) constituted the trial. Each pot contained 10 kg of soil on which was added 80 g of biochar corresponding to the proportions of 20 tons ha⁻¹. Two (2) incubation periods

of five (5) months were observed. At the beginning of each incubation period, the biochar was thoroughly mixed to the soil in the pots and left to incubate. During incubation, the soil was regularly irrigated. The same protocol was repeated for the second incubation period. At the end of each incubation period (first and second), soil samples were collected and analyzed according to laboratory protocol. Soil fertility parameters such as pH, electrical conductivity (EC), cation exchange capacity (CEC), bulk density, and soil penetration resistance were measured.

2.5 Statistical analysis

The multivariate analysis was conducted on the data collected using SPSS V.17.0 (SPSS 2008). Duncan means of treatments were separated using Duncan Multiple Range Test (DMRT) where their significant differences ($p < 0.05$) were observed.

3. Results and discussion

3.1 Effect of biochar application on soil pH

The application of various types of biochar produced at 300°C did not have a statistically significant impact on soil pH values during the initial incubation period. However, during the second period, the application of biochar did have a significant effect on soil pH ($p < 0.001$). Among the treatments, VB300 demonstrated the most effective leveling of soil pH, with 7.22 and 7.37 values compared to the control (7.44; 7.57) during the first and second incubation periods, respectively.

In contrast, the application of different types of biochar produced at 500°C did not significantly affect soil pH values during the first period. However, during the second period, the application of these biochar did have a significant effect on soil pH values ($p < 0.001$). Specifically, CB500 (7.25) and TB500 (7.45) exhibited the lowest pH values over both incubation periods compared to the control (7.44; 7.57).

Overall, these findings suggest that the application of biochar can have a notable impact on soil pH, with the specific effects varying depending on the type of biochar and the incubation period. The means of the pH results for each sample are presented in **Table 3**, and a boxplot of the pH results is presented in **Figure 1**.

After 300 days of incubation, it was found that the application of various biochar treatments produced at of 300°C and 500°C helped to stabilize the soil pH level compared to the control during the two incubation periods outside BB300, CB300, and CB500 [15]. The effect of biochar application on soil pH is strongly influenced by the type of biomass used and the pyrolysis process. There exists a close relationship between the pH of the biochar and the pH of the treated soil. The alkalinity of biochar plays a crucial role in regulating acidic soils [8]. Applying biochar to acidic soils would result in an increase in soil pH [16, 17]. Streubel et al. [18] demonstrated that the application of biochar derived from different herbaceous (pH 9.4) and woody (pH 7.4) plant sources led to pH changes in treated soils of 0.4–0.8 and 0.1–0.4 units, respectively.

3.2 Effect of biochar application on soil EC

The results of the application of various types of biochar produced at 300°C showed that the application of the different treatments did not have statistically

Treatment	Temperatures			
	300°C		500°C	
	I	II	I	II
Control	7.44	7.57AB	7.44	7.57AB
VB	7.22b	7.37aC	7.33	7.51BC
TB	7.25b	7.50aB	7.33	7.45BC
BB	7.45	7.53B	7.30b	7.49aBC
CB	7.39b	7.63aA	7.25b	7.60aA

Means with different small letters in a column are significantly different at the 5% level. Means with different capital letters in the row are significantly different at the 5% level. ns: not significantly different at the 5% level. Vineyard biochar (VB), Tomato biochar (TB), Banana biochar (BB), Carnation biochar (CB).

^{*}Significantly different at the 5% level.

^{***}Significantly different at the 0.01% level.

Table 3.
Effect of biochar applications on soil pH.

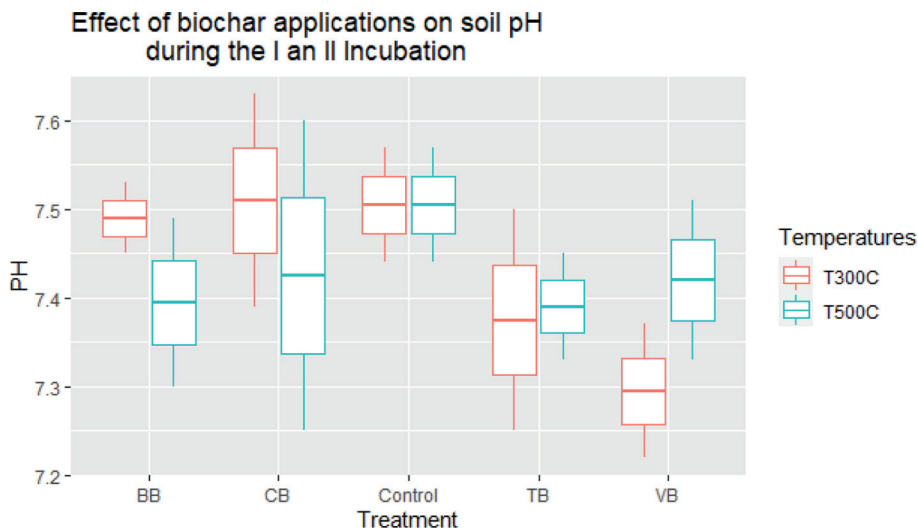


Figure 1.
Boxplot of pH measurements after biochar application. Upper and lower hinges correspond to 25th and 75th percentiles (1st and 3rd quartiles), respectively. Solid line corresponds to median. Whiskers extend to the highest and lowest values within 1.5 times the interquartile range.

significant effects on soil EC during the first incubation period. However, during the second application period, significant effects on soil EC ($p < 0.001$) were found. Among the biochar produced at 300°C, TB300 was the treatment that best improved soil EC relative to the control during the first and second incubation periods, respectively. Application of the different types of biochar produced at 500°C had no significant effect on soil EC during the first period. However, a statistically significant effect was observed on soil EC ($p < 0.001$) during the second incubation period. CB500 and TB500 were the treatments that best improved soil EC values over both incubation periods relative to the control. The means of EC results for each sample are presented in **Table 4**, and a boxplot of EC results is presented in **Figure 2**.

Treatment	Temperatures			
	300°C		500°C	
	I	II	I	II
Control	1.041	0.482aC	1.041	0.485B
VB	1.541a	0.518bBC	1.389a	0.488bB
TB	1.841a	0.868bA	1.623	0.893A
BB	1.022a	0.680bB	1.658	0.794A
CB	1.492	0.655aB	2.257a	0.783bA
LSD	0.3612 ns	0.0005***	0.2798 ns	0.0006**

Means with different lowercase letters in a column are significantly different at the 5% level. Means with different capital letters in the row are significantly different at the 5% level. ns: no significant difference at the 5% level. LSD: average of the five repetitions. Vineyard biochar (VB), Tomato biochar (TB), Banana biochar (BB), Carnation biochar (CB).

**Significantly different at the 1% level.

***Significantly different at the 0.1% level.

Table 4.
Effect of biochar applications on soil EC (dS m^{-1}).

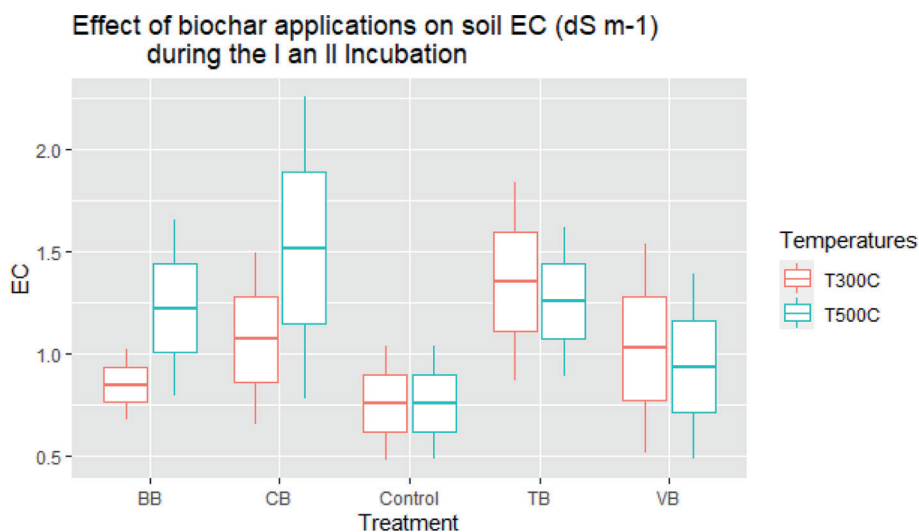


Figure 2.
Boxplot of EC measurements after biochar application. Upper and lower hinges correspond to 25th and 75th percentiles (1st and 3rd quartiles), respectively. Solid line corresponds to median. Whiskers extend to the highest and lowest values within 1.5 times the interquartile range.

At the end of the incubation period, although the soil EC values were low (less than 4 dS m^{-1}), the application of various types of biochar produced at different temperatures (300°C and 500°C) resulted in an increase on soil electrical conductivity values during the first and second incubation periods compared to the control. These values provide evidence that the soil is not saline [19]. This conclusion aligns with the similar results reported by [20].

3.3 Effect of biochar application on cation exchange capacity (CEC)

From the table, we observed the results obtained from the application of various types of biochar derived from different crop residues at 300°C temperature rate. These findings reveal that the application of these different treatments had a significant effect ($p < 0.01$) on soil CEC during the first incubation period. However, during the second incubation period, the treatments did not have a significant impact on soil CEC.

Among the biochar treatments produced at 300°C, TB300 and VB300 exhibited the most substantial enhancement in soil CEC compared to the control during the first and second incubation periods, respectively. On the other hand, the application of biochar produced at 500°C did not have a significant effect on soil CEC during the first period. However, during the first and second periods, biochar produced at 500°C demonstrated a significant effect at $p < 0.01$ and $p < 0.05$, respectively, on soil CEC. VB500 and CB500 were the treatments that displayed the greatest improvement in soil CEC values over both incubation periods compared to the control. In summary, the application of biochar derived from different agricultural residues pyrolyzed at different temperatures had varying effects on soil CEC. The treatments produced at 300°C showed significant improvements in soil CEC, while the treatments produced at 500°C had a significant impact on soil CEC during the second period. These findings highlight the potential of biochar application in enhancing soil properties and suggest that the choice of biochar type and pyrolysis process can influence its effectiveness in improving soil CEC. The means of CEC results for each sample are presented in **Table 5**, and a boxplot of CEC results is presented in **Figure 3**.

At the end of the incubation period, the application of biochar produced at different temperatures (300°C and 500°C) rate led to a noticeable increase in CEC values during the first and second incubation periods compared to the control (BB300, CB300, TB500, and BB500). Although these values remain relatively low (less than 20 meq 100 g⁻¹), this can be attributed to the type of clay present in the original soil.

Treatment	Temperatures			
	300°C		500°C	
	I	II	I	II
Control	7.49B	7.31	7.79C	7.31ABC
VB	9.75aA	7.90b	10.07aA	7.53bAB
TB	9.87aA	7.50b	8.40aBC	6.61bBC
BB	8.87aA	6.81b	8.99aB	6.20bC
CB	7.51B	7.10	8.90aB	8.04bA
LSD	0.0005***	0.4784 ns	0.0008***	0.0153*

Means with different lowercase letters in a column are significantly different at the 5% level. Means with different capital letters in the row are significantly different at the 5% level. ns: no significant difference at the 5% level. LSD: average of the five repetitions. Vineyard biochar (VB), Tomato biochar (TB), Banana biochar (BB), Carnation biochar (CB).

*Significantly different at the 5% level.

***Significantly different at the 0.1% level.

Table 5.
Effect of biochar applications on soil CEC (meq 100 g⁻¹).

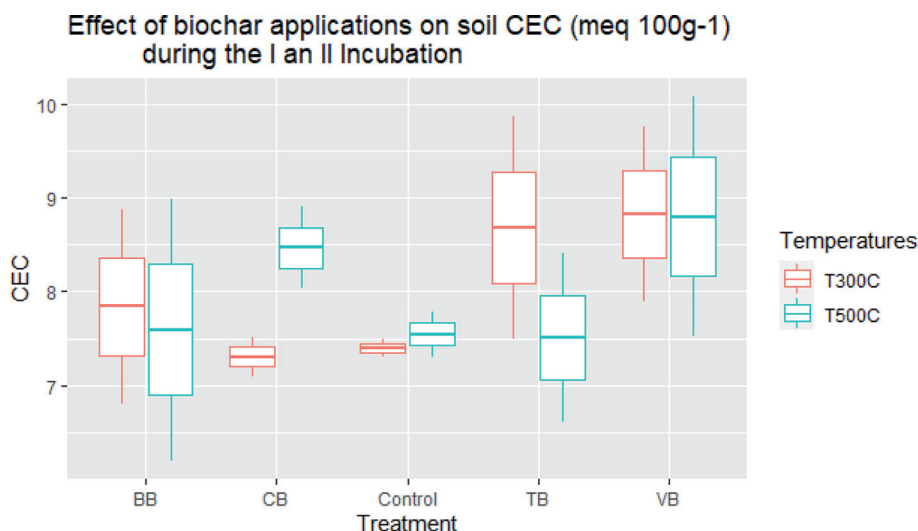


Figure 3.

Boxplot of CEC measurements after biochar application. Upper and lower hinges correspond to 25th and 75th percentiles (1st and 3rd quartiles), respectively. Solid line corresponds to median. Whiskers extend to the highest and lowest values within 1.5 times the interquartile range.

However, previous research by [21, 22] suggests that the specific surface area and pore structure of biochar can enhance soil CEC values when applied. In a study conducted by [23], it was found that the application of biochar derived from olive residues to a silt–clay–sand soil resulted in a 5% increase in CEC value. Similar studies in the literature, such as those by [3, 24, 25], have also reported significant increases in soil CEC following the application of biochar. Overall, these findings highlight the potential of biochar to improve soil CEC values, although further research is needed to fully understand the mechanisms behind this enhancement.

3.4 Effect of biochar application on bulk density

The application of various types of biochar, derived from different crop residues at 300°C, was found to have no significant impact on bulk density during the initial incubation period. However, during the subsequent incubation period, these treatments had a significant effect on bulk density. Among the biochar produced at 300°C, TB300 treatment was the most effective in reducing soil bulk density compared to the control, both in the first and second incubation periods. Furthermore, the biochar produced at 500°C showed a statistically significant effect, with p-values of less than 0.01 and 0.001% in the first and second incubation periods, respectively. Specifically, the TB500 and BB500 treatments exhibited the most substantial decrease in soil bulk density values in the first and second incubation periods, respectively, compared to the control. These findings emphasize the potential of biochar application, particularly at specific temperatures, to effectively reduce soil bulk density. This information is valuable for gaining insights into the impact of biochar on soil properties and can contribute to the development of sustainable agricultural practices. The means of the bulk density results for each sample are presented in **Table 6**, and a boxplot of the bulk density results is presented in **Figure 4**.

The application of various types of biochar derived from different crop residues at different temperatures rate (300°C and 500°C) led to a noticeable decrease in bulk

Treatment	Temperatures			
	300°C		500°C	
	I	II	I	II
Control	1.37b	1.45aA	1.37bA	1.45aA
VB	1.31	1.27B	1.32AB	1.29BC
TB	1.29	1.25B	1.26C	1.25C
BB	1.30	1.26B	1.30aBC	1.24bC
CB	1.34	1.29B	1.28 BC	1.33B
LSD	0.1202 ns	0.0009***	0.0028**	<0.001***

Means with different lowercase letters in a column are significantly different at the 5% threshold. Means with different capital letters in the lines are significantly different at the 5% level. ns: no significant difference at the 5% level. LSD: average of the five repetitions. Vineyard biochar (VB), Tomato biochar (TB), Banana biochar (BB), Carnation biochar (CB).

**Significantly different at the 1% level.

***Significantly different at the 0.1% level.

Table 6.
Effect of biochar applications on the bulk density (g cm^{-3}).

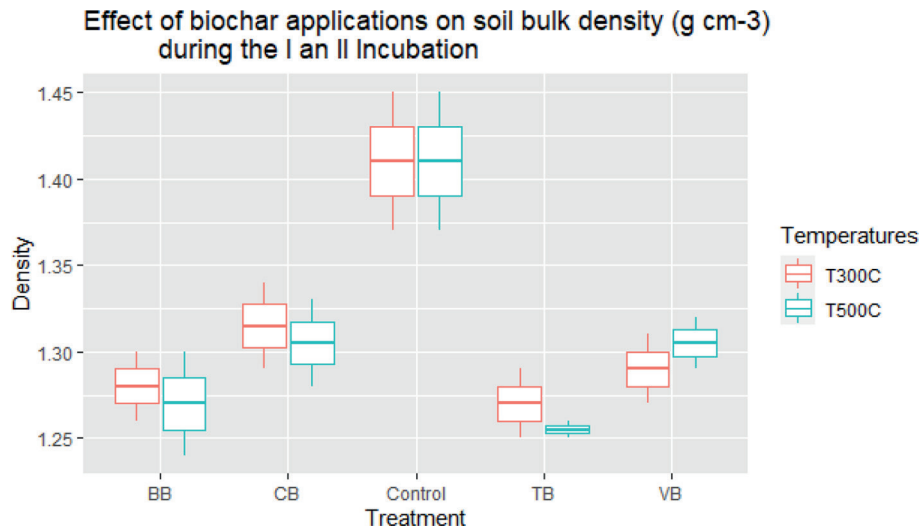


Figure 4.
Boxplot of bulk density measurements after biochar application. Upper and lower hinges correspond to 25th and 75th percentiles (1st and 3rd quartiles), respectively. Solid line corresponds to median. Whiskers extend to the highest and lowest values within 1.5 times the interquartile range.

density values during the first and second incubation periods compared to control. These findings align with the research conducted by [6, 26–28]. Moreover, similar results have been found in the literature studies [29–36].

3.5 Effects of biochar application on soil penetration resistance

From **Figure 5**, results showed a decrease in soil penetration resistance values after biochar application during the first and second incubation periods compared to the control. The application of these different treatments resulted in the soil

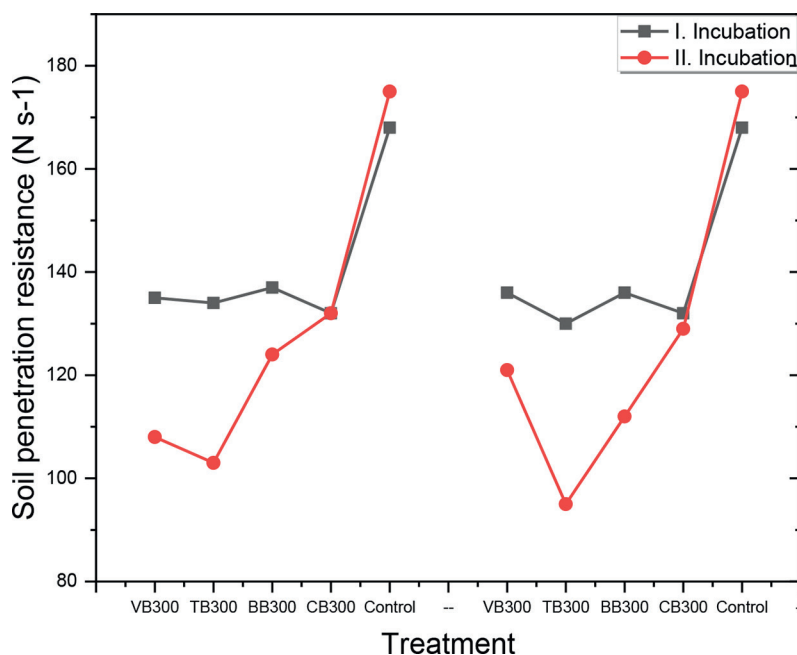


Figure 5.
Effects of biochar application on soil penetration resistance ($N s^{-1}$).

decompaction. Numerous studies have reported that applying biochar to soil causes a decrease in soil compaction [29, 31, 32, 37, 38]. Additional research conducted by [37, 38] also supports the thesis of notion that biochar application led to a decrease in soil compaction.

4. Conclusion

The study examined the impact of applying various types of biochar, derived from different agricultural residues through slow pyrolysis system at two different temperatures of pyrolysis, on specific soil fertility parameters. Results revealed a significant improvement in the fertility parameters of the treated soil. Firstly, the results demonstrated that the application of four biochar types VB, TB, BB, and CB, produced at two temperatures rate 300 and 500°C, effectively limed the soil pH levels in comparison with the control. Additionally, the electrical conductivity (EC) values also exhibited improvement as a result of the different treatments, surpassing those of the control. Moreover, the cation exchange capacity (CEC) values were significantly increased compared to the control. Furthermore, the application of these different treatments led to a reduction in the bulk density when compared to the control. Lastly, the various treatments applied successfully alleviated soil compaction by reducing the values of soil penetration resistance in comparison to the control soil. This study highlights the positive impact of applying different types of biochar, produced from various agricultural residues through slow pyrolysis system at different temperatures (300 and 500°C), on soil fertility parameters. The findings indicate improvements in soil pH levels, electrical conductivity, cation exchange capacity, bulk density, and soil decompaction. These results contribute to our understanding of

sustainable agricultural practices and the potential benefits of biochar application in enhancing soil fertility.

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