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Effect of Date Palm Derived Biochar on Soil's Bulk Density, pH, and Nitrogen Content

Aola H. F. Tahir[*a], **Faris H. Al-ani**[a], **Abdul Hameed M. J. Al-Obaidy**[b]

[a] Civil Engineering Dept., University of Technology-Iraq, Alsina'a street,10066 Baghdad, Iraq.
[b] Environment Research Centre, University of Technology-Iraq, Alsina'a street,10066 Baghdad, Iraq
*Corresponding author Email: 42189@student.uotechnology.edy.iq

HIGHLIGHTS

- Biochar is considered a suitable alternative for modifying and improving soil structure, bulk density, and porosity.
- Biochar's effect on nutrients and total nitrogen remarkably impacted soil fertility.
- A higher biochar application rate had a higher significant effect on each soil sample.
- Biochars produced at (250-350°C) have a minor impact on soil characteristics, whereas biochar produced at (450-550°C) had a higher effect on soil properties.
- Bulk density was decreased due to biochar's high porosity (up to 90%), while pH increased from 7.23 to 8.5.

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ABSTRACT

The use of biochar as a soil amendment has been the focus of many studies. It is believed to improve soil characteristics and increase crop yields. Still, a diverse range of feedstocks needs to be researched and converted to biochar for environmental purposes. To achieve sustainable biochar, it is favorable to be derived from residues available locally, and particularly interesting are those that have been turned to biochar near the application area. This study investigates the effects of locally date palm-derived biochars produced at four different temperatures (250, 350, 450, and 550°C) for 60 minutes on soil physicochemical properties, mainly; pH, bulk density, and total nitrogen availability. The biochar application ratios were 5% and 10% by weight to each soil sample. The soil was gathered from a local farm near Al-Kargoulia, textured as clay loam, and had a total nitrogen content of 25 mg/kg. From mixing through incubation, the experiment lasted 30 days. Biochars produced at (250-350°C) have a minor impact on soil characteristics, whereas biochar produced at (450-550°C) had a higher effect on soil properties. Bulk density was decreased due to biochar's high porosity (up to 90%), while pH increased from 7.23 to 8.5. In contrast, nitrogen was affected highly and increased to 32.33 mg/kg.

1. Introduction

Improving soil's physical, chemical, and biological characteristics using biochar as a soil amendment has gained considerable interest. Biochar reduces greenhouse gas emissions and sequesters carbon by eliminating organic carbon from the photosynthetic and decomposition cycles [1]. Biochar produced by pyrolysis and charcoal made by natural combustion had similar properties due to their similar converting conditions and led to long soil residence time and soil conditioning impact. According to studies, biochar from geological deposits can increase soil organic carbon (SOC), improve plant nutrient availability, and improve plant development and soil physical, chemical, and biological qualities [2].

Biochar can change soil structure, pore size distribution, and density, affecting aeration, water holding capacity, plant growth, and soil workability. As a result, soil water and nutrient retention may be improved [3]. In addition, biochar can improve overall net soil surface area as it reduces net repulsive soil internal forces and thus stabilizes soil aggregates [4] and reduces soil bulk density, which is beneficial to plant growth [5].

The feedstock availability and composition are two of the most critical parameters influencing biochar's efficient and cost-effective manufacturing. These factors directly affect the yield of biochar rather than its quality. Each country has its source of feedstock, such as agricultural leftovers, urban trash, paper waste, woody biomass, aquatic biomass, animal and human excreta, industrial waste, food and kitchen waste, dairy and paper mill waste, chicken waste, and others. Therefore, proper categorization and characterization are essential for efficient use [6].

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

Agricultural waste is being generated at a continuous rate all over the world. Agriculture waste is composed of cellulose, hemicellulose, and lignin. In contrast, cellulose is the most abundant organic material on earth, and plants' cellulose production is approximately 1011-1012 tons per year. Lignin polymer presents the aromatic alcohols in its structure. In addition to its important role in plants, it has a biological and ecological function [6].

Lignin covers gaps between cellulose, hemicelluloses, and pectin components in the cell wall, particularly in tracheid, sclereid, and xylem cells. These components are suitable for biochar production through pyrolysis. Biochar application has proved in several studies that it is effective in tropical zones where soils are acidic, and leaching of nutrients occurs more often [7]. When these soil conditions exist, biochar works as a liming and nutrient affection, increasing the pH and improving nutrient bioavailability [8]. Biochar can function as an adsorbent, decreasing nitrogen leaching and boosting nitrogen usage efficiency [9]. Due to the surface binding of cations and anions to biochar's surfaces, its porosity and surface area plays an essential role in sustaining soil nutrients. The high NH_4^+ adsorption on biochar [10] can minimize nitrogen volatilization, improve soil fertility [11], and encourage plant growth and development [12]. The date palm (Phoenix dactylifera L.) is one of the world's most important fruit trees, growing in tropical, subtropical, and dry climates from North Africa to the Middle East. Each palm tree generates around 20 kilograms of dry leaves annually, while date pits account for almost 10% of date fruits. Recently, there has been an increase in interest in processing these residues, particularly in the Middle East. A review of the most recent published literature regarding date palm-derived biochar has been done in a previous paper [13]. Several research revealed that date palm waste has high calorific values, high volatile content biomass components, and a noteworthy HHV compared to other agricultural wastes. As a result, date palm waste could be considered a valuable chemical product and a beneficial supply [14, 15, 16]. Bensidhom et al. FTIR analysis of biochar and bio-oil revealed that it was primarily made up of aromatic and aliphatic components [14]. This study incorporated biochar date palm tree residue (trunk, leaves, and seed) derived biochar (obtained from an unpublished study) in clay loam soil at different rates. The aim is to evaluate the effect of these biochar samples on bulk density, pH, and nitrogen content to suggest further additional applications.

2. Materials and Methods

2.1 Biochar and Soil

The theoretical section extends the analytical background of the article and develops a new formulation of the problem. Calculations are achieved here using the developed equations, and the modifications should be pointed out. Two soil samples were used in the experiment: At a depth of 30 cm, the soil was gathered from a private farm near Alkargoulia in Baghdad, Iraq, and soil from an agriculture plantation. The soil was mixed and analyzed for its diverse characteristics. The soil was sieved through a 2mm sieve to remove larger soil aggregates. Soil texture was determined depending on volumetric particle size and was found to be clay loam with an E.C of 3.9 dS/m and pH 7.23. Soluble ions were determined by titration and using a flame photometer. Other parameters analyzed are found in Table 1. Date palm residue (trunk, leaves, and seed) is gathered from the same site during the trimming season of the trees.

Further information about the raw material can be found in a previously published work [13]. Trunk, leaves, and seeds of the date palm tree were converted to biochar through a pyrolysis system at four different temperatures (250. 350, 450, and 550ºC) for 60 minutes in an inert atmosphere with a heating rate of less than 10ºC/min. Biochar was stored in covered glass containers for later use. The biochar shown in Figure 1 produced had the following characteristics:

Ash (9.67-24.54%)
Carbon content (45.86-82.36%)
Porosity (65.63-90.28%)

Table 1: Properties of the soil used in the experiment

Parameter	Unit	Soil sample
Organic matter	g/kg	7.8
$CaCO_3$	g/kg	298.12
Ca^{2+}	mEq/l	8.7
Mg^{2+}	mEq/l	6.4
Na^+	mEq/l	4.67
Soluble HCO_3	mEq/l	1.3
Soluble Cl	mEq/l	17.4
Soluble K	mEq/l	1.23
N	mg/kg soil	25
P	mg/kg soil	2.44
K	mg/ kg soil	254.12

Figure 1: Biochar samples used from left, trunk biochar (TB), leaves biochar (LB), and seed biochar (SB)

2.2 Experimental Setup and Methods

The soil was weighed and separated into different pots. Biochar was added at two different rates (5% and 10%) from 12 biochar samples. These ratios were chosen after reviewing a wide range of papers with similar goals. The samples were labeled as the following TB250, TB350, TB450 and TB550 for trunk derived biochar produced at different temperature (250, 350, 450 and 550oC), and similar for leaves (LB250, LB350, LB450 and LB550) and seed biochar (SB250, SB350, SB450 and SB550). Irrigation was performed on a schedule to maintain the moisture content in the soil. The pots were incubated in a 25^{o}C environment. Samples were taken after 30 days of mixing. Soil physical and chemical analysis was done before biochar addition, and pH, bulk density, and total nitrogen were measured after 30 days of addition. pH was determined using a pH meter (1:1 ration), and total nitrogen was measured using the Micro Kjeldahl technique All results are shown in Table 2 and 3.

3. Results and Discussions

3.1 Bulk Density

Bulk density is an important factor of soil quality, production efficiency, compacting, and porosity. It is considered to be suitable for soil compaction estimation. Bulk density decreased slightly with 5% biochar addition derived from all three feedstocks, as shown in in Figure 2. This decrease in bulk density may be due to several reasons. It is generally related to the porosity of the biochar and the main characteristics of the soil. The biochar can also create soil aggregates with soil particles, which also leads to bulk density decrease and porosity increase. Trunk-derived biochar at 550^{o}C had the highest bulk density decrease. It had the highest biochar porosity percentage (90.28%). Biochar produced at 250-350^{o}C had less effect on soil due to less porosity and active pores. Biochar addition has been proven to decrease bulk density and increase soil water content and crop yield, as stated by previous literature [17,18]. The formation of soil aggregates is a key progression since it presents the association between the mineral and other organic soil particles due to hydroxyl and carboxyl groups on the biochar particles' surface [19]. This suggests the applicability of the biochar for the treatment and removal of contaminations in soil. Microorganisms in the soil play a key role in the formation and stability of aggregates. The synthesis of hydrophobic compounds by microbes improves aggregate repellency, reducing soil wetness and affecting aggregate stability. Rice husk biochar increased soil aggregate stability and drastically reduced Cd availability in soil and uptake in maize, according to a recent study [20]. The bulk density variation did not endure a major effect at a higher biochar application ratio. The effect of biochar for reducing bulk density on clayey soils can be smaller than that on sandy soils because the difference in bulk density between biochar (~0.6 g/cm^{-3}) and clayey sols (~1.1 g cm^{-3}) is smaller than that between biochar (~0.6 g/cm^{-3}) and sandy soils (~1.5 g/cm^{-3}). Soil fauna is enriched with biochar and attracts digestive earthworms, leading to coprolites that are agronomically valuable soil aggregates. These conditions prefer a low bulk density soil structure which biochar also conducts.

3.2 pH

Overall, in low-temperature derived biochar, lower pH values were observed. This slight reduction could be explained by decomposable composites of organic biochar, which release hydrogen ions from carboxylic functional groups and give an acidic affection [21,22]. These biochar samples are likely similar to raw feedstock and contain higher ratios of O/C and H/C, which indicate higher values of total surface acidic biochars produced at higher temperatures.

It has previously been observed that biochar produced from pine through pyrolysis and black carbon is not always inert in soil and can be oxidized by chemical and microbiological processes [23,24]. At biochar samples derived at a higher temperature, the pH was increased. This is attributed to the liming potential of biochar due to its high pH and base cation, which is the typical specification of biochar produced at a temperature over 550^{o}C. Biomass feedstocks and pyrolytic conditions primarily influence biochar characteristics. For example, biochar made from leguminous feedstocks has a greater liming potential than biochar made from non-leguminous feedstocks [25]. Legumes accumulate more alkali in their plant biomass during growth due to the unbalanced uptake of cations and anions compared with non-legumes [26]. In an incubation experiment done by Liu and Zhang [24] to explore the influence of biochar application on the pH of alkaline soils, biochar treatment resulted in a lowering trend in soil pH, especially when application rates were increased. Therefore at a higher application ratio, there wasn't a substantial alteration. Response absence of pH in treated soil may be due to clay's buffering effect and the low amount of biochars applied. Still, seed-derived biochar at 550oC increased soil pH at both application rates Figure 3.

3.3 Total Nitrogen

Nitrogen is a significant component of organic compounds in crops and an essential component of all living creatures. Nitrogen in soil is mostly bound, so total nitrogen is used to measure soil nitrogen and crop growth nitrogen availability. Biochar is believed to increase alkaline nitrogen, the accessible nitrogen that plants can absorb directly [27]. Biochar produced at higher temperatures tends to contain oxygen-containing functional groups on the surface of biochar (-OH, -C=O, -O-), which will participate in the adsorption process of different compounds. In this study, biochar increased nitrogen availability in the soil and minimized the losses. As shown in Figure 4, adding 5% biochar increased the nitrogen content (0.2-12%) while 10% biochar added the total nitrogen significantly (2-29%). Because of its porous structure and high surface area, biochar has been shown to retain nitrogen and enhance soil nitrogen in several experiments [28,29]. However, too much biochar addition may risk occurring if nitrogen surplus. Therefore an optimum biochar amendment level must be specified to maintain an ideal soil nitrogen availability. Biochar appears capable of absorbing N via ion exchange, removing NH3 via adsorption, and stimulating immobilization with flow-on effects on NO3 leaching [30]. Several studies showed that biochar application considerably improved total organic and total nitrogen, especially storage of these components in the aggregates size fractions [31]. The biochar also contains energy substances to act as a microbial substrate for direct nitrogen adsorption applied to increase accumulated total nitrogen [32].

Table 2: Biochar addition (5%) in soil

Sample	TB250	TB350	TB450	TB550	LB250	LB350	LB450	LB550	SB250	SB350	SB450	SB550
pH	7.5	7.2	7.73	8.04	7.9	7.1	7.8	8.13	7.9	7.92	7.57	8.5
Total N (mg/kg)	25.13	25.77	27.22	28.33	25.03	26.11	26.92	27.22	26.84	27.34	28.83	28.19
Bulk density	1.5	1.48	1.22	1.19	1.49	1.42	1.31	1.22	1.51	1.39	1.32	1.33

Table 3: Biochar addition (10%) in soil

Sample	TB250	TB350	TB450	TB550	LB250	LB350	LB450	LB550	SB250	SB350	SB450	SB550
pH	7.66	7.51	7.78	8.1	8.21	8.11	8.61	8.4	7.42	8.22	8.1	8.52
Total N(mg/kg)	25.53	26.75	26.98	30.94	25.38	27.33	27.99	31.83	26.84	28.88	29.73	32.33
Bulk density	1.48	1.45	1.2	1.13	1.47	1.4	1.31	1.16	1.49	1.35	1.28	1.25

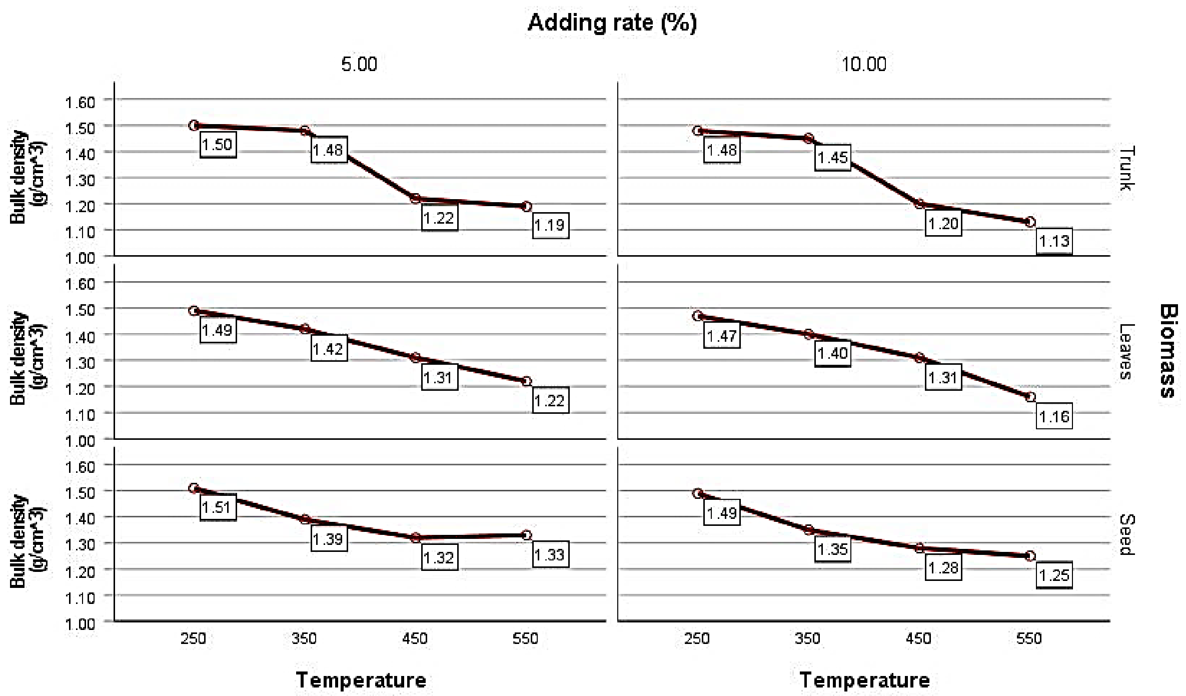

Figure 2: Derived biochar effect on soil's bulk density

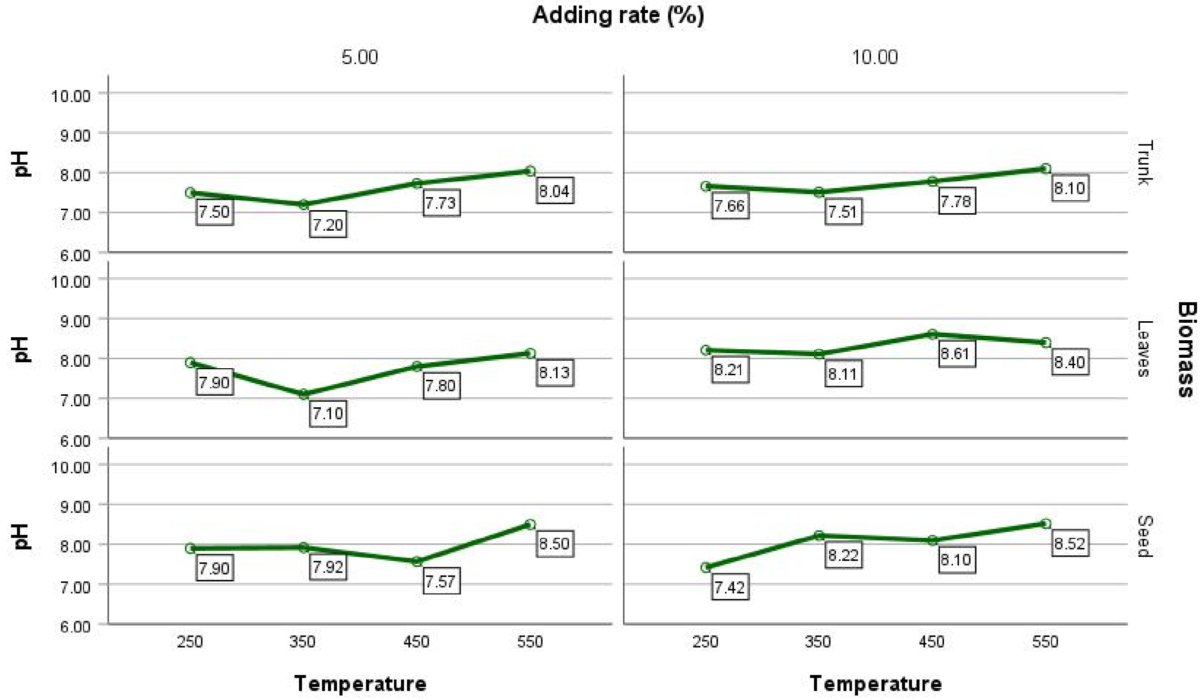

Figure 3: Derived biochar effect on soil's pH

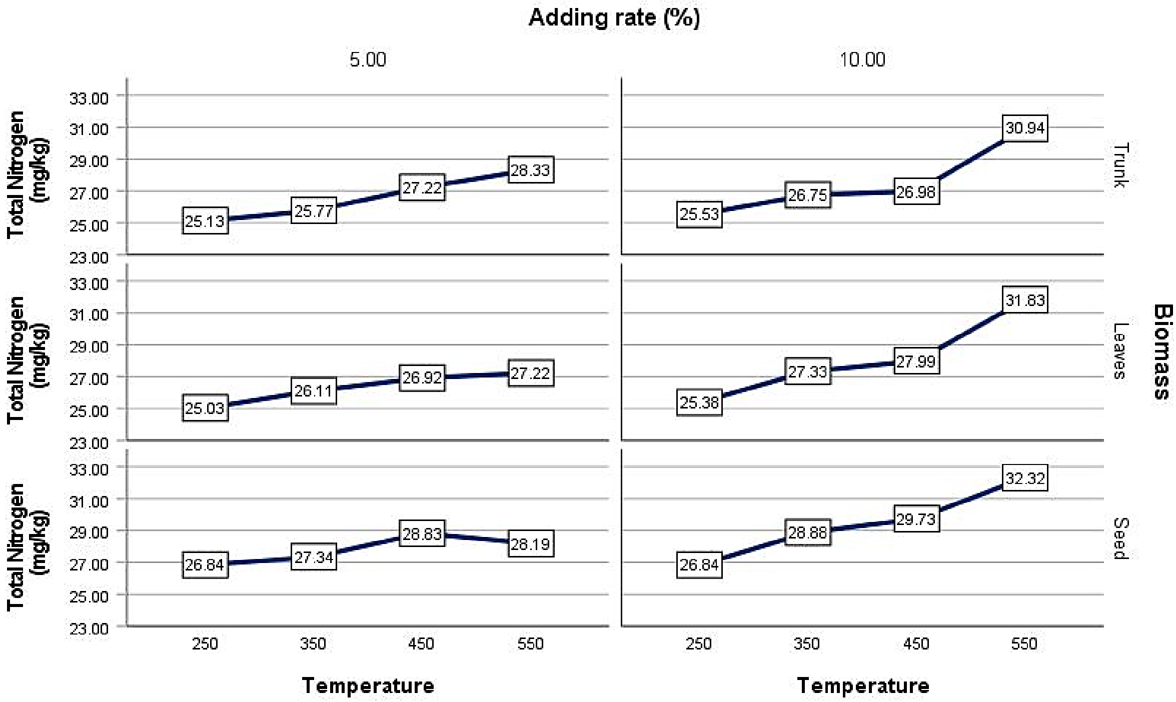

Figure 4: Derived biochar effect on soil's total nitrogen

4. Conclusion

The use of biochar is considered a suitable alternative for the modification and improvement of soil structure, bulk density, and porosity. It offers a favorable environment for improved water and nutrient flow, retention in the soil profile, and increased root system growth, resulting in higher crop yields. The bulk density of soil decreased due to the low density of biochar particles and its influence on soil pores rearrangement and the creation of new accommodation pores. Soil aggregation was affected positively, which is important in determining soil quality and erosion resistance. Biochar's affected the soil's pH slightly. It could be concluded that biochar may have a higher effect on acidic soils than on neutral ones. Biochar's effect on nutrients and total nitrogen remarkably impacted soil fertility. Future studies regarding additional locally made biochars from available feedstock and residues and their incorporation in different types of soils may be implemented alongside investigating its crop yield influence.

Author Contribution

Methodology, Faris H. M. Al-Ani; Software, Aola H. F. Tahir; Formal Analysis, Abdul Hameed M. J. Al-Obaidy, Writing-Original, Draft Preparation, Aola H. F. Tahir; Writing-Review & Editing, Faris H. M. Al-Ani; Abdul Hameed M. J. Al-Obaidy "All authors have read and agreed to the published version of the manuscript."

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

Authors declare that their present work has no conflict of interest with other published works.

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