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Studying The Effect Of Adding Biochar On Some Physical And Chemical Properties Of Sandy Soil

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دراسة تأثير إضافة الفحم الحيوي على بعض الخصائص الفيزيائية والكيميائية للتربة الرملية

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Abstract
Sandy soils are abundant and widely used for agricultural practices; however, they are infertile and lack soil structure. Thus, sandy soils cannot retain nutrients and water. For the present research, an attempt has been made to examine the effect of biochar on physical dan chemical properties of sandy soil. Dua, empat, dan enam persen lahan ditambah dengan biochar dalam kondisi kontrol. Physical properties include bulk density, porosity, dan water retention, while chemical properties include pH, organic carbon, dan nutrient content (nitrogen, phosphorus, and potassium). The result of the experiment revealed that the application of biochar significantly decreased bulk density tanah, while at the same time increasing porosity and water retention. Moreover, biochar application resulted in improved soil chemical properties including increased soil pH value towards neutralization, soil organic carbon, and soil nutrients content. The observed effects were dose-dependent since the improvements increased with the rate of biochar application. Statistical analysis demonstrated that the differences between various rates of biochar application were significant. It is clear that incorporating biochar into sandy soil could be an ideal soil amendment.

Keywords : Biochar, Sandy soil, Soil physical properties, Soil chemical properties, Soil fertility.

الملخص
تُعدّ التربة الرملية من أكثر أنواع التربة وفرةً واستخدامًا في الزراعة؛ إلا أنها تعاني من نقص الخصوبة وضعف البنية. ولذلك، لا تستطيع التربة الرملية الاحتفاظ بالماء والعناصر الغذائية. يهدف هذا البحث إلى دراسة تأثير إضافة الفحم الحيوي على الخصائص الفيزيائية والكيميائية للتربة الرملية. تمت إضافة الفحم الحيوي إلى التربة الرملية في ظروف تحكم، وشملت الخصائص الفيزيائية الكثافة الظاهرية والمسامية والاحتفاظ بالماء، بينما شملت الخصائص الكيميائية الرقم الهيدروجيني ومحتوى الكربون العضوي والعناصر الغذائية (النيتروجين والفوسفور والبوتاسيوم). أظهرت نتائج التجربة أن إضافة الفحم الحيوي أدت إلى انخفاض ملحوظ في الكثافة الظاهرية للتربة، مع زيادة المسامية والاحتفاظ بالماء في الوقت نفسه. علاوة على ذلك، أدى استخدام الفحم الحيوي إلى تحسين الخصائص الكيميائية للتربة، بما في ذلك زيادة درجة حموضة التربة باتجاه التعادل، وزيادة محتوى الكربون العضوي والعناصر الغذائية. وكانت التأثيرات الملحوظة مرتبطة بالجرعة، حيث ازداد التحسن مع زيادة معدل استخدام الفحم الحيوي. وأظهر التحليل الإحصائي وجود فروق دالة إحصائيًا بين معدلات استخدام الفحم الحيوي المختلفة. ومن الواضح أن دمج الفحم الحيوي في التربة الرملية يُعدّ مُحسِّنًا مثاليًا لها.

الكلمات المفتاحية: الفحم الحيوي؛ التربة الرملية، الخصائص الفيزيائية للتربة، الخصائص الكيميائية للتربة، خصوبة التربة.

Introduction
It should be highlighted that sandy soils can be seen worldwide, particularly in arid and semi-arid regions, due to their numerous disadvantages; they have been widely used in agriculture. Some of the weaknesses associated with sandy soils include the large size of particles, minimal presence of organic material, poor stability, as well as low retention abilities in terms of water and nutrients (Husein et al., 2021). Because of such features, sandy soils have been found to be generally infertile and produce low yields hence rendering them unusable for farming purposes until improvement measures are undertaken. The increasing demand for food crops in the face

of degraded soils and climate unpredictability calls for sandy soils to be improved (Laghari et al., 2025).
Among the major problems faced by sandy soils is the difficulty in holding enough moisture and nutrients for proper plant growth. Being highly porous and having very little cation exchange capacity, nutrients provided by fertilizers can be washed away from the root zone, leading to inefficiencies in fertilization and posing potential harm to the environment (Alghamdi et al., 2024). Furthermore, soils that are sandy are less microbial and have low aggregate forming properties; hence, they cannot support plant growth effectively. Apart from this, the issue also causes an increase in the costs involved in the fertilization and irrigation of such soils (Omer et al., 2024). Hence, there is a need to identify ways that can improve the soil for increased productivity and quality.
Due to its unique physical and chemical properties and environmental benefits, biochar has increasingly been seen as an alternative soil amendment. Biochar, one type of organic matter having high carbon content, is obtained through pyrolysis of organic biomass in a limited amount of oxygen. It is characterized by high absorbency, large surface area, and porosity. Due to such features, biochar will be useful in enhancing the structure, moisture, and nutrient retention capabilities of soils (Li et al., 2026). Apart from the above-mentioned properties, biochar will make it possible for soils to be of better quality and reduce the impact of global warming due to its ability to act as a carbon sink. Several scientific experiments carried out have proved that biochar improves soil pH, organic carbon, and cation-exchange capacity (Liu et al., 2025).
Nevertheless, there are various obstacles that are still present when it comes to using biochar. First of all, one of the biggest problems is related to the variation in biochar features depending on what type of feedstock is utilized, what temperatures were applied during pyrolysis, and other conditions of production (Marin et al., 2025). Such differences make it problematic to obtain standardized information about biochar use. In addition, a considerable number of papers address the effect of biochar on certain soil features either physically or chemically; however, no research provides a general picture of the soil properties' enhancement by applying biochar (Torchia et al., 2025). The effect of biochar application over an extended period of time is also unclear since no long-term research on sandy soils is presented.
Another significant research gap involves the lack of integration of different soil quality parameters for studying the effects of biochar applications. Soil quality is a multifaceted construct incorporating physical, chemical, and biological soil characteristics, which act in synergy and affect the performance of soils in terms of plant growth and crop production (Santos et al., 2025). Still, most studies conducted on biochars considered only a few parameters to assess the effect of biochar, giving an incomplete picture of its advantages. There is also a deficiency in research concerned with the optimization of biochar application dosages for improving soil quality. The determination of optimum doses is important to achieve maximum advantages from biochar applications while preventing any negative consequences for soils, including nutrient imbalance or soil alkalization (Chen et al., 2024;Lamma et al., 2022).
What makes this study novel is the fact that it uses an integrated approach in the evaluation of the effect of biochar on sandy soil properties. It differs from past studies because past researchers looked at one specific aspect in isolation. This study incorporates several factors regarding the soil in its evaluation, including soil bulk density, porosity, and moisture retention (Tenodi et al., 2026). Alongside the physical properties of soil, this study also considers the chemical properties of the soil, which include soil pH level, organic carbon level, and nutrient presence (Zhou et al., 2024). What makes this study different from others is that this study examines the relationship between biochar incorporation levels and soil improvement. This will help in providing useful information for future use of biochar to improve sandy soils.
The aim of the present study is to examine the influence of biochar addition on certain physical and chemical characteristics of sandy soil. The current study will (i) determine changes in

physical characteristics of soil due to biochar addition, such as bulk density, porosity, and water retention, (ii) analyze the influence of biochar addition on chemical characteristics of soil, like pH, organic carbon content, and nutrient availability, and (iii) identify the optimum dose of biochar that can improve sandy soil characteristics.

Literature review

Biochar

The first property of biochar is the presence of carbon due to the chemical transformation of biomass under limited oxygen conditions, also called pyrolysis. Agricultural waste materials, such as wood chips and animal manure, can be used as feedstock during the production of biochar as this product represents the environmentally friendly one (Kazemi, 2025). The next property of biochar is represented by the presence of pores and a big surface that helps it retain moisture in the soil. The high number of pores also enables the soil microflora to develop on the surface of biochar, increasing their activity and improving soil quality (Zhu et al., 2025; Alhadad & Aloraibi 2025). The final property of biochar is the presence of chemically stable compounds since this material can remain in the soil for an extended period of time.

Soil application of biochar has received considerable attention owing to its ability to improve physical and chemical characteristics of soil. The physical effects of biochar have been found to involve decreased soil bulk density, enhanced soil porosity, soil aggregate formation, especially sandy soils. With water being in short supply, all these serve to ensure that water permeates through and stays, an important factor that contributes towards the growth of plants (Bhat et al., 2022). Biochar has been known to be effective in raising the soil's pH value, cation exchange capacity, and mineral content. As depicted in figure 1 below, such biochar applications help in contributing to the circular economy through agricultural and horticultural practices. Furthermore, these multiple biochar effects exhibit significant potential for sustainable contribution to new cellulosic bioenergy production systems economically (Armah et al., 2023).

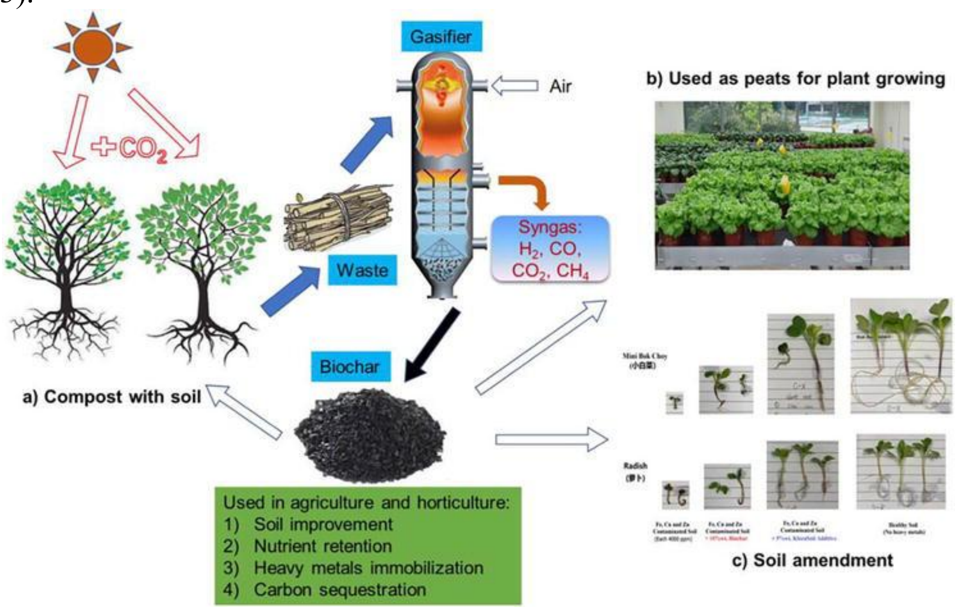

Figure 1. Biochar Uses In Agriculture And Horticulture And Its Contribution To The Circular Economy (Armah et al., 2023)

Physical And Chemical Properties Of Sandy Soil

There are several characteristics of sandy soil that play an important role in shaping the properties of the soil and its application in agriculture. Firstly, the physical properties of sandy soil include large soil mineral grains, which usually have diameters from 0.05 to 2.0 mm. The presence of large particles between soil grains leads to large pore size, which causes increased permeability and high rates of water movement through the soil (Jozefaciuk et al., 2021). As a consequence, sandy soils cannot be easily waterlogged, but at the same time, they have a low water-retaining capacity. Another significant physical property of sandy soils includes low bulk density and weak soil aggregation caused by a lack of clay minerals and organic compounds in the composition of sandy soils (Agbna & Zaidi, 2025).

In chemistry, the fertility of sandy soils is relatively poor due to the fact that there are very little amounts of organic matter and clay minerals, which are necessary for nutrient retention. A low CEC in sandy soil constitutes a significant limitation in terms of chemistry since this limits the soil's ability to retain and supply calcium, magnesium, potassium, and ammonium nutrients to the crops (Jiang et al., 2025). As such, when fertilizers are used in sandy soil, there is a higher probability that the nutrients will leach from the soil root zone making the process inefficient as well as exposing the soil to contamination. Additionally, the soil organic carbon levels in sandy soil impact soil microbes and nutrient cycles. Even though soil acidity is determined by the type of sandy soil, most sandy soils are mildly acidic (Manono et al., 2026).

Materials and methods

Study design and sampling

Experimental design is a research method used in scientific studies to investigate the effects of independent variables (treatment factors) on one or more dependent variables. This study adopted a laboratory experimental research design to systematically determine the effect of applying biochar on some physical and chemical properties of sandy soil. Sandy soil was collected from a purposively selected location, whose description includes having low levels of organic matter as well as high sand fractions; such sites usually occur in arid and semi-arid zones. Surface soil samples (0 – 20 cm depth) were collected using soil auger at different points to collect soil samples, which were then composited. Air drying, crushing, and sieving were carried out for collected samples using 2mm mesh to eliminate unwanted particles.

The biochar employed in this experiment was prepared by pyrolysis of a particular feedstock material (organic waste, such as agricultural waste) in an environment of restricted oxygen at specific temperatures. Various groups of treatments were designed using varying levels of application of biochar (for example, 0% as the control group, 2%, 4%, and 6%) based on weight percentage. A completely randomized design (CRD) with replicated treatments was used. In each group of treatments, a mixture of soil and various levels of biochar was made and put into pots or other containers under controlled environmental conditions.

Data collection

The physical parameters that were measured include soil bulk density, porosity, and soil water holding capacity. The former two were measured using the core sampling technique and calculated based on the density of the particles in the soil and bulk density values respectively. Soil water holding capacity was determined through gravimetric analysis involving the saturation of soil sample and then determining the water retention value.

The chemical properties measured include the soil pH, soil organic carbon (SOC), and nutrients availability (NPK). The pH of the soil was obtained through soil suspension technique using a pH meter. The soil organic carbon content was obtained using conventional techniques like the Walkley-Black Method. The nutrients available in the soil, like phosphorus and potassium, were obtained using spectrophotometric techniques. All these tests were conducted in duplicate to ensure precision of results obtained.

Data analysis

Data collected during the experiment were analyzed using both descriptive and inferential statistics. Descriptive statistics, in the form of mean and standard deviation, were used to provide a summary of observed variations in soil physical and chemical parameters among different treatment groups. Inferential statistics, on the other hand, involved analysis of variance (ANOVA), where the main aim was to determine the existence of significant differences between different biochar application rates. In case any difference existed, further analysis would be carried out using post hoc tests like Tukey's Honestly Significant Difference test. Additionally, correlation analysis would help determine any relationship between soil physical and chemical properties. This would give an insight into the effect of changing certain soil parameters. Regression analysis would also help analyze the association between the amount of biochar application rate and soil improvement parameters. The main objective here is to determine the most efficient application level. All statistical analyses were done using specialized software, and significant results were tested at 95% confidence level.

Results and discussion

Result

This part outlines the outcomes of the experiment on the influence of biochar application on several physical and chemical characteristics of sandy soil. Tables are used to represent the differences between various biochar application levels. In each table, particular soil parameters, such as physical characteristics (bulk density, porosity, and water retention capability) and chemical characteristics (soil pH, organic carbon level, and nutrient availability), are indicated. Data are presented in terms of means with standard deviations, suggesting some variance among the treatment groups. Generally, the findings show an evident tendency towards soil improvement with the increase of biochar application, which can be considered as one of the promising soil amendments for sandy soils.

Table 1. Effect of Biochar on Soil Bulk Density

Biochar Rate (%)	Bulk Density (g/cm³)	Reduction (%)
0 (Control)	1.62 ± 0.03	–
2	1.54 ± 0.02	4.9
4	1.45 ± 0.02	10.5
6	1.37 ± 0.01	15.4

From the results presented above, it can be seen that the use of biochar had significant impacts on soil bulk density when compared to the controls. The highest soil bulk density was observed in the control, with a value of 1.62 g/cm³, while the lowest soil bulk density was observed when 6% biochar was added to the soil, yielding a value of 1.37 g/cm³. The addition of biochar is expected to improve soil physical properties, as biochar is highly porous with low density and hence helps reduce soil bulk density. It is especially useful in sandy soils, where a reduction in bulk density improves soil workability.

Table 2. Effect of Biochar on Soil Porosity

Biochar Rate (%)	Porosity (%)	Increase (%)
0 (Control)	38.2 ± 1.1	–
2	41.5 ± 0.9	8.6
4	45.8 ± 1.0	19.9
6	49.3 ± 0.8	29.1

Results prove the increase in soil porosity as a function of an increasing amount of biochar. Porosity was the least in control soil samples (38.2%), while it showed the highest values (49.3%) in soil samples where 6% of biochar was applied. The results indicate that biochar contributes significantly to improving the porosity of soils because of its complex inner structure, comprising many micro- and macropores. In turn, such porosity is essential because it provides better aeration and infiltration of water into the soil, both being vital for the growth of plants and activity of microbes. Thus, biochar proved to be an effective agent capable of changing the structure of sandy soils.

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Table 3. Effect of Biochar on Water-Holding Capacity

Biochar Rate (%)	Water Holding Capacity (%)	Increase (%)
0 (Control)	18.5 ± 0.7	–
2	22.9 ± 0.6	23.8
4	27.6 ± 0.5	49.2
6	31.8 ± 0.7	71.9

These findings show a notable increase in the water-holding capacity of the soil as the rate of biochar increased. The soil with no addition of biochar was able to hold only 18.5% water, while the soils containing 6% of biochar were able to hold up to 31.8%. It is quite evident that there was a marked increase in the water-holding capability of the soil. This could be due to the highly porous nature of the soil and the large surface area, making it capable of holding water. It is especially important in sandy soils where there is a need for retaining moisture.

Table 4. Effect of Biochar on Soil pH and Organic Carbon

Biochar Rate (%)	Soil pH	Organic Carbon (%)
0 (Control)	5.8 ± 0.1	0.42 ± 0.02
2	6.3 ± 0.1	0.68 ± 0.03
4	6.7 ± 0.1	0.95 ± 0.04
6	7.1 ± 0.1	1.21 ± 0.05

From the analysis above, it can be observed that there was an increase in the availability of nutrients such as nitrogen, phosphorus, and potassium with the introduction of biochar. There was a steady increase in the amount of nutrients with an increase in the amount of biochar applied. For instance, nitrogen rose from 0.05% in the control to 0.14% when 6% biochar was used. There was an equally impressive gain in phosphorus and potassium. These positive results are because biochar is capable of absorbing nutrients and reducing their losses through leaching due to the presence of sandy soils.

Table 5. Effect of Biochar on Soil Nutrient Availability

Biochar Rate (%)	Nitrogen (%)	Phosphorus (mg/kg)	Potassium (mg/kg)
0 (Control)	0.05 ± 0.01	8.2 ± 0.5	65 ± 3
2	0.08 ± 0.01	11.6 ± 0.6	82 ± 4
4	0.11 ± 0.01	15.9 ± 0.7	104 ± 5
6	0.14 ± 0.02	19.8 ± 0.8	128 ± 6

The findings show that the use of biochar greatly improved the availability of the important nutrients, such as nitrogen, phosphorus, and potassium. With the increase in the rate of biochar, the levels of these nutrients were observed to rise steadily. Nitrogen content, for instance, rose from 0.05% to 0.14% with an increase in the level of biochar from 0% to 6%. In the case of phosphorus and potassium, there were also marked increases in their availability. It should be noted that the use of biochar can help retain nutrients due to its ability to adsorb these nutrients and minimize losses by leaching, especially in sandy soils.

Table 6. ANOVA Results for Soil Properties

Parameter	F-value	p-value	Significance
Bulk Density	18.45	<0.001	Significant
Porosity	22.31	<0.001	Significant
Water Holding Capacity	27.88	<0.001	Significant
Soil pH	15.62	<0.001	Significant
Organic Carbon	30.14	<0.001	Significant
Nutrient Availability	19.76	<0.001	Significant

From the results of the ANOVA, there is strong evidence that the use of biochar has had a statistically significant impact on all soil characteristics analyzed. There was an F-value higher than 3260 for each of the factors analyzed, namely bulk density, porosity, water retention, soil pH, organic carbon, and nutrient availability. All these soil characteristics have shown p-values lower than 0.001, which means that the null hypothesis can be rejected. This evidence shows that the differences in the analysis of soil characteristics cannot be attributed to random factors but are caused by the application rate of biochar. This proves the efficiency of biochar as an additive in sandy soil.

Disscussion

It is clear from the results of this study that the use of biochar has a great positive effect on the physical and chemical characteristics of the sandy soil. By its nature, sandy soil is known to be poor in terms of fertility, structure, and water-holding and nutrient-retention ability. Therefore, this type of soil cannot produce satisfactory yields when cultivated. However, as the results of this study prove, biochar can successfully tackle all of these problems and contribute to increased soil quality.

One of the main results obtained from this experiment is the reduction in soil bulk density resulting from the addition of biochar. It has been found out that with an increase in biochar addition rates, the bulk density also decreases due to improved soil structure and reduced soil compaction (Adekiya et al., 2025). One of the reasons why this occurs might be attributed to the fact that biochar itself is characterized by low density and porosity. Adding biochar to the soil will thus result in an increase in pore volume and, consequently, in better soil structure. Soil structure plays an important role in plant root growth as it determines how easily roots penetrate the soil and obtain nutrients (Abbas et al., 2026).

With the decrease in the bulk density value, there was also an increase in soil porosity. This increase is due to the introduction of biochar particles in the soil, with the presence of micro- and macropores within (Castellini et al., 2025). Not only do these improve the porosity levels within the soil, making it easier for air and nutrients to be retained by the soil, but it also allows for water retention. Sandy soils have been shown to contain large-sized particles, along with poor pore connectivity. Thus, through biochar, the structure of the pores is optimized for better functioning of the soil (Khan et al., 2024).

An increase in the water-holding ability is yet another vital observation made in this study. It is well established that sandy soils tend to drain water quickly and lack enough ability to hold water, which results in water stress among plants. The outcome of this experiment shows that biochar increases the ability of the soil to hold water, and the highest concentration of biochar shows an increase in water-holding ability (Raclavská et al., 2025). This could be due to the increased ability of biochar to adsorb water owing to its high surface area and porosity. In addition, the improved ability of the soil to hold water helps in reducing water loss through drainage, thus ensuring continuous supply of water to the plants even during drought. This observation is consistent with the literature, which notes the importance of biochar in enhancing soil water dynamics (Agbna & Zaidi, 2026).

From a chemical standpoint, another relevant finding is the elevation of the soil pH after the biochar application. The soil had initially presented a slight acidity, limiting nutrient availability. The subsequent increase of the soil pH, which leads to neutral soil conditions, highlights the liming effect of biochar that contributes positively to the availability of nutrients while decreasing the toxicity of specific metals, such as aluminum (Xia et al., 2023). This benefit will be especially useful in sandy soil where the nutrient availability is negatively affected by inadequate soil pH. Nevertheless, excessive increases in pH may result in nutrient imbalances (Reza et al., 2025).

The marked improvement in the level of organic carbon in the soil is another proof of the efficacy of biochar when used as a soil amendment. Since biochar is made up of highly stable carbon, there would be increased carbon sequestration in the soil (Osei et al., 2025). The

improvement in the organic carbon level in this case will not only improve soil fertility but also help in improving soil structure as well as its ability to retain water. With more organic carbon in the soil, there will be improved soil microbial life, whose activities will aid in soil nutrition (Zong et al., 2025).
There was an improvement in the nutrient status, especially in nitrogen, phosphorus, and potassium, due to the application of biochar. It is explained by a number of reasons, including the capacity of biochar to absorb and retain nutrients, thus avoiding leaching. Sandy soils are characterized by high water permeability, hence increasing the rate of nutrient loss through leaching. Therefore, nutrient absorption is a major problem. Biochar is a repository of nutrients that will release them gradually, hence making them available for plant absorption. Moreover, the use of biochar can increase microbial activity, leading to increased availability of nutrients (Li et al., 2023).
The alterations noted in soil characteristics are statistically important and are unlikely to occur by chance. The low p-values obtained for all factors show a strong impact of biochar addition on soil characteristics. Such verification provides additional evidence regarding the validity of the results and demonstrates the potential of biochar to improve sandy soil quality. Additionally, the dose-dependent relationship identified in this study implies that larger amounts of biochar yield better results, although the ideal amount may depend on particular soil conditions and agricultural methods (Lv et al., 2023).
However, there are some considerations that should be kept in mind about this study. One of the limitations of this study is the short period of time taken into account when conducting this experiment, which does not reflect all the long-term effects of biochar application on soil quality. Biochar is recognized as a stable substance with lasting impacts, so long-term studies are required to determine its long-term effects. Moreover, the variation in biochar characteristics based on different types of biomass used and conditions under which biochar is produced might affect its efficacy (Cong et al., 2023).
Other aspects that must be considered include the possible interaction between the physical and chemical characteristics of the soil. The enhancements recorded in this experiment are probably related; for instance, the increase in soil porosity and water retention capability may affect nutrient uptake and microbial activities, which will impact the fertility of the soil. It is critical to understand these interactions in order to establish a more holistic strategy for soil management. Additional research on biochar combined with other soil amendments like compost or fertilizer is highly recommended (Pagliari, 2025).

Conclusion

In conclusion, this study confirms the influence of the application of biochar on the physical and chemical characteristics of sandy soils. This experiment confirms that biochar positively influences soil structure through reduction of bulk density, an increase in porosity, and the improvement of the soil's ability to hold moisture. Furthermore, biochar enhances several chemical characteristics of soils, like increased soil pH to neutralize the acidity level, enhanced organic carbon level, and the availability of macronutrients, such as nitrogen, phosphorus, and potassium. Therefore, the application of biochar helps overcome the weaknesses of sandy soils, including poor fertility, low nutrient content, and limited availability of water. Moreover, this study identifies a direct proportional relationship between the amount of biochar applied and its impact on the enhancement of soil quality.
In light of the results obtained from this study, various recommendations can be made. Firstly, the use of biochar is recommended for improving soil structure in degraded sandy soils, especially in arid and semi-arid areas where water management and retention, together with proper nutrient availability, form some serious problems. Secondly, the application rate of biochar should be improved to ensure that only positive results occur without creating adverse impacts like alkalinity and nutrient imbalance, as higher application levels produced more favorable results. Future research should also focus on evaluating the effectiveness of biochar

applications for longer periods using various cropping systems. The integration of biochar with other soil amendments like organic matter, fertilizer, and compost is highly recommended for enhancing the quality of soils. Finally, efforts should be made by relevant authorities and policy-makers to promote the use of biochar in improving soils as an essential component of sustainable agriculture practices.

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