

***Acacia nilotica* Biochar Improves Sandy Soil Structure and Stimulates Root Development in Muscat Grape**

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Abstract. *The effectiveness of biochar as a soil amendment is well recognized for improving soil fertility and plant root architecture. However, its beneficial effects on root development in perennial woody species require further investigation. In this 14-week greenhouse experiment, we evaluated the effects of *Acacia nilotica*-derived biochar on soil physical properties and Muscat grape growth. Muscat grape plants were grown in sandy soil amended with four biochar rates, 4%, 8%, 12%, and 16%, based on dry soil weight. Soil properties and root traits were then assessed. The results showed that adding 16% biochar to sandy soil reduced soil bulk density by 41%, increased total porosity by 51%, and improved water holding capacity by 1.11 times compared with sandy soil without biochar. Biochar incorporation also reduced soil acidity and improved soil buffering capacity, resulting in a more favorable soil pH several months after application. In addition, biochar stimulated fine root development, significantly increasing root length, root crossings, and root forks while reducing average root diameter. Overall, *Acacia nilotica* wood waste can be converted into valuable biochar for improving sandy soil quality and promoting grape root development. This approach supports waste recycling, improves soil physical conditions, enhances grape growth, and contributes to circular economy-based agriculture. Therefore, *Acacia nilotica*-derived biochar can be recommended as a promising soil amendment for Muscat grape cultivation, particularly in sandy soils where improved water retention and root growth are needed.*

Keywords: *Acacia bark-biochar, Muscat grape, Ultisol soil, root structure, soil amendment*

Introduction

Biochar is a stable carbon-rich material produced through the thermal decomposition of biomass under limited oxygen conditions (Yuan et al., 2026). Its application as a soil amendment has received increasing attention because it can improve soil water retention, nutrient availability, cation exchange capacity, porosity, and overall soil fertility (Liu et al., 2023). These benefits are especially important in sandy soils, which often have low organic matter, weak nutrient retention, poor aggregation, and limited water holding capacity. By improving soil structure and resource availability, biochar can create a more favorable root zone environment and support plant growth (Wang et al., 2024a).

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Plant roots are the primary interface for water and nutrient acquisition, and their architecture strongly determines plant establishment, stress tolerance, and productivity (Abubakar et al., 2023). Biochar can influence root growth indirectly by improving soil aeration, water availability, nutrient retention, and microbial activity. It may also affect root traits directly through changes in rhizosphere chemistry and root-soil contact (Wang et al., 2024b). Root length, surface area, diameter, branching, crossings, and forks are important indicators of how efficiently plants explore the soil and acquire resources (Zeng et al., 2024). However, most biochar studies have focused mainly on soil chemical properties (Jin et al., 2026), aboveground biomass, or crop yield, while root architectural responses have received comparatively less attention.

This knowledge gap is more evident in perennial woody crops, including grapevine (Su et al., 2023), where root development plays a long-term role in water uptake, nutrient acquisition, canopy growth, and productivity. In grapevines, the balance between aboveground growth and root system development is critical for plant performance, especially in sandy soils with poor water and nutrient retention (Fu et al., 2026; Hou et al., 2026). Although biochar has been widely evaluated in annual crops and short-term soil fertility studies (Suo et al., 2026), its role in modifying fine root development and root system architecture in perennial fruit crops remains insufficiently understood. Muscat grape is an economically important grape cultivar cultivated for fresh consumption and juice production. It can adapt to warm growing conditions, but its growth and productivity can be constrained by poor soil structure and low water retention, particularly in sandy soils (Li et al., 2022). Improving root zone conditions may therefore support better root proliferation, resource uptake, and plant establishment. *Acacia nilotica* wood waste is produced in considerable quantities and can be converted into biochar, offering a sustainable option for soil improvement and biomass waste management. Therefore, this study evaluated the effects of *Acacia nilotica*-derived biochar applied at different rates on sandy soil physical properties and root architecture of Muscat grape under greenhouse conditions. We hypothesized that biochar incorporation would improve soil structure, reduce bulk density, increase porosity and water holding capacity, and promote finer and more extensive root development. The study aimed to clarify whether biochar-mediated changes in sandy soil properties can enhance root traits in Muscat grape and provide a sustainable strategy for grape cultivation in low-fertility sandy soils.

Materials and Methods

Experimental Design and Relationship Between Pot and Column Experiments

Two complementary greenhouse experiments were conducted to evaluate the effect of *Acacia nilotica*-derived biochar on sandy soil properties and Muscat grape root development. The pot experiment was designed to assess plant growth, root architecture, and soil physical traits under a wider root zone condition. The column experiment was designed to provide a more vertically constrained rooting environment, allow controlled drainage, support leachate collection, and evaluate root development and pH changes under conditions that better represented downward root exploration. Both experiments used the same biochar rates, irrigation regime, fertilization practice, and ambient greenhouse conditions to ensure comparability between the two systems.

Biochar Treatments and Application Rate

Acacia nilotica-derived biochar was incorporated into sandy soil at 0, 4, 8, 12, and 16% on a dry weight basis. The 0% treatment served as the control. These relatively high biochar rates were selected because sandy soil has low organic matter, weak aggregation, poor nutrient retention, and limited water holding capacity. Therefore, a broad biochar gradient was required to detect clear changes in soil physical properties and root architectural responses. The highest rate was included to determine whether great improvement in porosity and water retention could support root development or whether excessive biochar addition might restrict root penetration by altering pore space and aeration.

Pot Experiment

In the pot experiment, Moscatello grape plants were grown individually in 6.1 L pots filled with the prepared biochar and soil mixtures. The experiment was arranged in a randomized complete block design with five treatments and six replications. Each replicate contained one pot, and each pot was considered the experimental unit for statistical analysis. When two plants were present in one pot, plant-level measurements were averaged before analysis so that the pot remained the experimental unit.

Column Experiment

In the column experiment, white polyethylene columns were filled with the same five biochar and soil mixtures used in the pot experiment. Fine wire mesh was fixed at the bottom of each column to prevent soil loss while allowing free drainage. One Moscatello plant was established in each column. The column experiment was maintained under the same greenhouse conditions, irrigation schedule, and fertilization regime as the pot experiment. Each column was considered the experimental unit for statistical analysis. At the end of the experiment, all plants were harvested destructively for root and aboveground trait measurements.

Irrigation and Fertilization Management

Plants were maintained under greenhouse conditions with an air temperature of 17 to 27 °C. Irrigation was applied through drip irrigation three times daily. The irrigation volume was adjusted according to plant growth stage, increasing from 120 mL day⁻¹ during early growth to 240 mL day⁻¹ during intermediate growth and 360 mL day⁻¹ during the final growth period. Plants received a weekly nutrient solution containing nitrogen, phosphorus, potassium, and trace elements. The same irrigation and fertilization practices were applied to all treatments in both pot and column experiments.

Quantification of Soil Characteristics

A digital laboratory thermometer with a stainless-steel probe was employed to measure the soil temperature in pots monthly, precisely at a depth of 15 cm. Subsequently, in the column investigation, irrigation was manually initiated for 30 minutes, and leachate was collected monthly to assess the pH level during three months. A 50 mL sample of exudates was extracted from the lower section of each column and subsequently transported to the laboratory for pH measurement at ambient temperature utilizing a pH meter. Soil samples collected from pots evaluated soil physical properties, including water holding capacity (WHC), porosity, and bulk density. The gravimetric analysis of soil moisture was performed on the composite samples collected from each plot following the assessment. The samples were subjected to air-drying and thoroughly blended.

To avoid the loss of biochar or soil, the soil samples, each weighing 50 g, were carefully weighed and placed into funnels lined with filter paper. Deionized water was used to saturate all filter sheets. After that, 50 mL of water was incrementally added to every soil sample. The leachate water was collected in a beaker for 30 minutes until there was no more drainage at room temperature. To reduce water loss through evaporation, a plastic wrap was placed over the funnel top. The soil water holding capacity was calculated using a known volume of leachate water, as described by Yin et al. (2022).

$$\text{WHC} = \frac{\text{added total water} - \text{volume of water run down}}{\text{Soil sample dry weight}} \times 100\% \quad (1)$$

At the end of the trial, the bulk density of soil was measured using a single pooled sample from every treatment. The calculation of total porosity was performed using the bulk densities of soil, as expressed using the following equation:

$$P = \frac{\text{Volume of voids}}{\text{Total volume}} \times 100\% \quad (2)$$

The P denotes the total porosity. This equation can also be transformed into:

$$p = \left(1 - \frac{BD}{PD}\right) \times 100\% \quad (3)$$

The PD and BD represent the particle density and bulk density, respectively. The calculation of the density of soil particles (PD) can be determined using the following method:

$$PD = \frac{\text{Sample mass}}{\text{Sample volume}} \times 100\% \quad (4)$$

Nonetheless, for every soil sample, the density of soil particles is always presumed to be $2.65/\text{g cm}^{-3}$. This allows us to compute total porosity in the following way:

$$p = \left(1 - \frac{BD}{2.65/\text{g cm}^{-3}}\right) \times 100\% \quad (5)$$

Root Structure Determination

The roots in the pots were segregated by bisecting the containers from both sides. In the research column, columns were systematically arranged, and roots were meticulously extracted by hand. Subsequently, the roots were submerged in tap water, cleansed with a moderate water flow, and then soaked in deionized water until they were prepared for scanning. The overall root length, specific root length, average root diameter, crossing number, and root volume were quantified utilizing a root scanner and WinRHIZO software.

Data Analysis

Data from the pot and column experiments were analyzed separately. For the pot experiment, the pot was considered the experimental unit. For the column experiment, the column was considered the experimental unit. Plant measurements taken from more than one plant within the same pot were averaged before statistical analysis. Data were analyzed using the GLIMMIX procedure in SAS. Treatment effects were tested using Type III fixed effects, and means were separated using the Tukey Kramer test at $p \leq 0.05$. Diagnostic plots were used to verify normality and homogeneity of variance.

Results and Discussion

Assessment of Soil Characteristics

The data obtained from the initial two determinations indicated A negative relationship between applied biochar rate and soil temperature (Table 1). Nevertheless, third measurement exhibited a declining pattern, albeit without any statistically significant difference observed between the groups. The findings were consistent with previous research in which soil thermal conductivity underwent a considerable reduction of 7.5% and 3.5% with $9 \text{ Mg ha}^{-1}\text{yr}^{-1}$ and $4.5 \text{ Mg ha}^{-1}\text{yr}^{-1}$, respectively, when the biochar amount increased (Al-Issa et al., 2026). The observed negative relationship between applied biochar rate and soil temperature can be attributed to biochar's ability to alter soil physical properties, particularly its thermal conductivity and WHC. Biochar's porous structure can reduce soil thermal conductivity, leading to decreased heat transfer and a more stable soil temperature (Alsanhani, 2026). Additionally, biochar can increase soil water retention, which can also contribute to a more stable soil temperature. The reduction in thermal conductivity with increasing biochar amount is consistent with previous research, suggesting that biochar can effectively insulate the soil and reduce temperature fluctuations (Ameen et al., 2026). This mechanism can have implications for plant growth, microbial activity, and overall soil health. The lack of statistically significant differences in the third measurement may be due to various factors, such as changes in environmental conditions or experimental variability (Arif et al., 2025). This finding was similarly in line with the observed reduction in the bulk density of soil. According to other study findings, biochar's application

can effectively manage high temperatures of the soil, resulting in a decrease in temperature during periods of higher soil temperature and an increase in temperature during periods of low soil temperature (Bashir & Mahmud, 2025). The capacity of soil daily average temperature and diurnal range to be adjusted was predominantly within a range of 0.4 and 0.8 °C, respectively. The mechanism by which biochar regulates the temperature of the soil can be comprehended by the combined effect of alterations in soil reflectance and thermal conductivity.

Table 1

Soil temperature was monitored sequentially throughout June, July, and August

Application rate of biochar, %	20 June	20 July	20 August
0	25.9 ^a	29.8 ^a	31.3 ^a
4	25.6 ^{ab}	29.2 ^{ab}	31 ^a
8	24.3 ^c	29.2 ^{ab}	30.8 ^a
12	24.8 ^{bc}	28.9 ^b	30.8 ^a
16	24.5 ^c	29 ^{ab}	30.9 ^a

Table 2 indicates a decrease in soil bulk density, along with a gradual rise in total porosity and WHC as the biochar application rate escalated. The use of biochar markedly diminished bulk density and enhanced soil porosity (Etik, 2025). Increasing biochar concentration in soils resulted in decreasing soil bulk density. Higher amount of biochar can be reasoned to affect soil bulk density by four primary mechanisms, (i) densification by small biochar particles occupying soil pores or by slaking/dispersion of aggregates causing fewer macropores between aggregates, (ii) dilution by soil volume occupied by a lower density material, (iii) increase in macropores between aggregates; and, (iv) introduction of accommodation pores between (large) biochar particles and the soil matrix (Faiyue et al., 2026).

Consequently, wood-based biochar substantially influences soil porosity in contrast to manure-derived biochar, which possesses notable ash content. A notable positive correlation between the biochar application rate and water-holding capacity was seen when the acacia-biochar treatment dosage was below 16% can be attributed to the increased porosity and surface area provided by the biochar. As the biochar application rate increases, the number of pores and surface area available for water retention also increases, leading to improved water-holding capacity. This can have beneficial effects on plant growth, especially in water-limited environments, by reducing soil moisture fluctuations and improving drought tolerance. The optimal application rate of 16% or lower may be related to the specific properties of the acacia-biochar and the soil type, highlighting the importance of considering these factors when applying biochar as a soil amendment. The water-holding capacity of soil supplemented with 16% biochar was 53%, whereas pure sandy-soil had a water-holding capacity of just 29%. Applying biochar resulted in a substantial rise of over 51% in water-holding capacity than the control group. Soil water holding capacity was enhanced by 1.3% through amount for each 1% biochar application over the agriculturally applicable range up to 16% biochar dose, because a higher amount of biochar addition was the reason for improvement. It was attributed to the internal porosity of biochar (biochar pore size <10 µm), which determines its ability to store water in the soil. This is because biochar replenishes water as it is removed by gravity, trapping water in pores, reducing hydraulic conductivity, and increasing water retention. According to the findings, the water-holding capacity of loamy sand soil that was mixed with various proportions of pinewood-derived biochar exhibited a positive relationship with the percentage of biochar treatment for biochar levels that were below 10% (Fatima et al., 2024). Furthermore, it was observed that the rise in water-holding

capacity per unit of biochar was higher when the amount of biochar was below 10%. However, it remained constant at 12% when the amount of biochar was over 10%. The observed trend can be attributed to the saturation of soil pores. At lower biochar application rates (below 10%), biochar effectively increases soil porosity, providing additional sites for water retention and significantly improving water-holding capacity. However, as the application rate exceeds 10%, soil pores become saturated, and additional biochar does not provide further significant increases in water-holding capacity. The constant 12% increase at higher rates suggests a threshold beyond which additional biochar does not provide proportional benefits, likely due to the existing pores being filled and excess biochar not contributing to further improvements in soil structure. Therefore, it has been proposed that a 10% amendment enhances the water retention capacity of a 1% biochar sample. A study found that standard deviation exhibited minimal variation in biochar rates up to 20%, but gradually rose as the biochar amendment level increased (Gavin et al., 2026).

Table 2
Measurement of soil qualities obtained from the soil that remains after harvesting

Application rate of biochar, %	Total porosity, %	Bulk density gcm ⁻³	Water holding capacity %
0	46	1.51	29
4	55	1.31	35
8	61	1.10	41
12	63	1.03	47
16	68	0.91	53

The water-holding capacity (WHC) (n = 3) and bulk density were assessed from un-sieved soil specimens at the end of trial. Total porosity was determined from bulk densities, assuming a particle density of 2.66 g/cm³ for soil minerals. Three replicate specimens from every treatment pool were utilized to assess statistical uncertainty.

Alteration of biochar has two impacts on soil water holding capacity. Firstly, biochar possesses the ability to retain water within its internal pores, so directly enhancing the moisture content of the soil. Previous research on straw-derived biochar verified that pores ranging in diameter from 0.1 to 10 µm in biochar increase the amount of water available to plants. Moreover, other parameters, including hydrophilic functional groups and total pore volume on the biochar surface, could potentially enhance soil water-holding capacity. However, it is essential to note that these benefits may be constrained due to the minimal quantity of biochar incorporated into the soil. Table 2 demonstrates that the incorporation of *Acacia*-biochar particles can decrease the total bulk density of sandy soils. According to a study, small particles of biochar had a greater impact on reducing the sandy soil's bulk density, but larger biochar particles had a greater impact on reducing the bulk density of loamy sand soil (Haq et al., 2022). Murtaza et al. (2024) assert that decreasing the particle size of biochar may improve water retention; however, this may lead to a drop in saturated water outflow. Murtaza et al. (2021) indicated that the variations in bulk density observed throughout the incubation period following biochar application did not consistently demonstrate statistical significance. The alterations in the bulk density of mixed soil can be ascribed to the comparatively low bulk density of biochar. The study provided data on soil physical parameters and biochar, demonstrating that biochar often results in a decrease in soil bulk density of 3–3%, an increase in porosity of 15–60%, and an improvement in wet aggregate stability of 5% to 230%. Biochar demonstrates a superior ability to improve the properties of sandy soils relative to clay soils (Molua & Nwachuku, 2026).

There is a clear correlation between biochar's influence on soil physical qualities and Moscatello's growth. The penetration depth and the availability of water and air in the root zone primarily depend

on the soil's physical makeup. Furthermore, it may affect the soil's ability to adjust to pH alterations, permeability during expansion, cation retention, aggregation capacity, and dynamics (Nepal et al., 2025). Table 3 displays the leachate's pH values. The pH value of the soil utilized in the present research was 5.8. The measurements conducted in May showed a positive correlation between the amount of biochar and the leachate pH. The leachate pH was reduced during the July evaluation, which can be attributed to the utilization of N fertilizer. The leachate pH rose during the September evaluation, mainly due to irrigation. The leachate pH treated with biochar after four months ranged from 6.51 to 6.93. The pH, which is 6.9, was close to the optimal pH for Moscatello growth. After five months, the pH of the leachate from the control treatment soil started to stabilize at approximately 6.6, but the pH of the leachate from the altered soil reached a stable level of around 7.1. The increase in pH in the biochar-treated soil to around 7.1 may be due to the biochar's ability to neutralize soil acidity and release basic cations. This pH shift can have implications for nutrient availability and microbial activity, potentially contributing to the observed positive effects on plant growth. The stable pH levels in both treatments suggest that the soils had reached a new equilibrium, with the biochar-treated soil maintaining a slightly higher pH. This finding matches a multitude of research studies that have demonstrated the positive impact of biochar on the pH levels of acidic soils (Rai et al., 2026).

Furthermore, the pH level of the soil may influence nutrient availability. The optimal phosphorus availability is observed at a pH of roughly 6.5. Phosphorus converts insoluble aluminum/phosphorus minerals at low pH, whereas it generates calcium-phosphate solid minerals at elevated pH levels. Furthermore, acidic soils have diminished the availability of magnesium, calcium, and potassium as a result of leaching (Shoukat, 2025). The findings of three measurements suggest that the pH of the leachate in the control had an increasing tendency over time.

Conversely, the pH levels of the biochar treatments remained consistent. The results indicated that the incorporation of biochar ameliorated soil acidity and augmented the soil's capacity to stabilize pH levels. The incorporation of biochar in acidic soils primarily improves their pH buffering capacity by facilitating the deprotonation and protonation of oxygenated functional groups inherent in the biochar (Suyanto et al., 2026). The functional groups containing oxygen can receive and donate protons via a conjugation reaction at lower pH values and a dissociation reaction at higher pH (Wijyanti, 2025).

Table 3

The soil pH was monitored monthly from May to September 2023 using leachate in column research

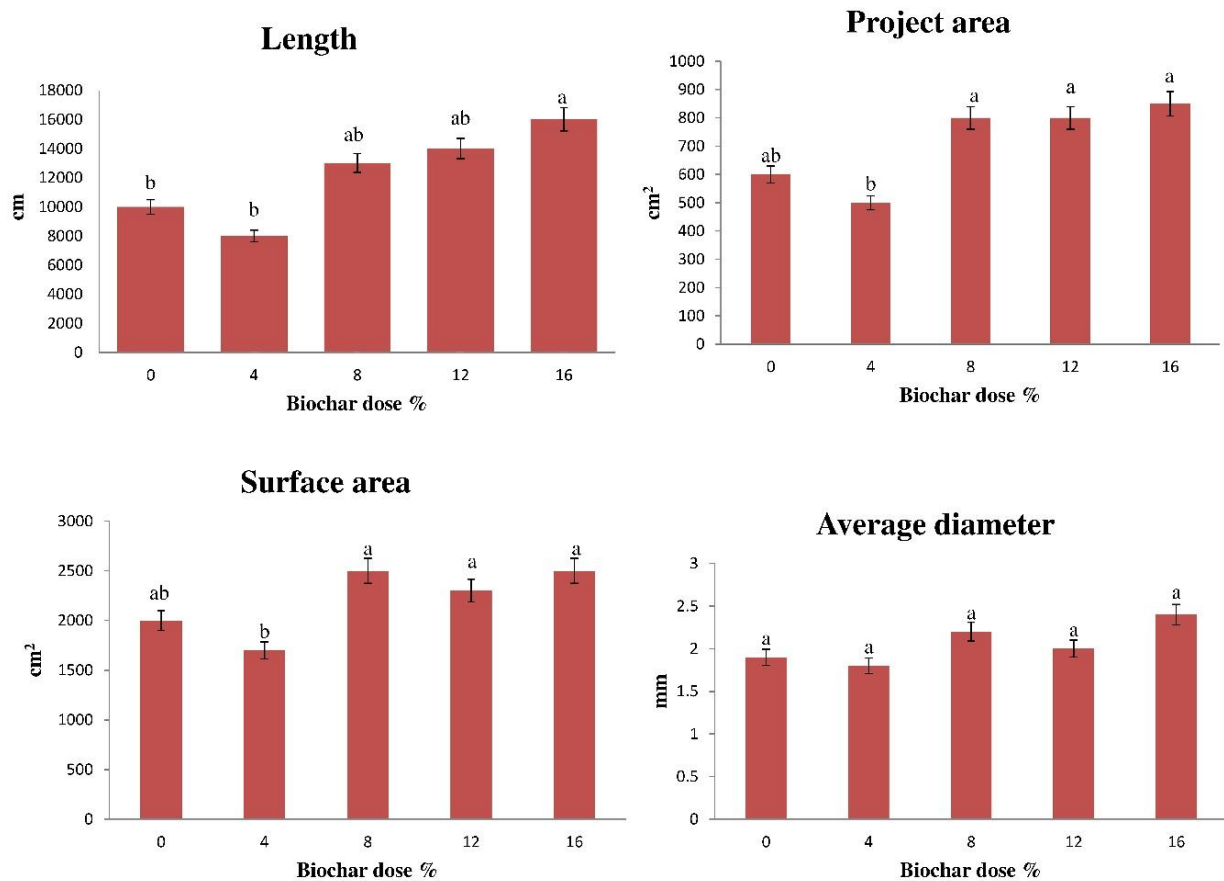
Application rate of biochar, %	20 May	20 July	20 September
0	5.69 ^d	4.93 ^c	6.31 ^b
4	6.51 ^c	6.39 ^b	6.77 ^{ab}
8	6.84 ^b	6.87 ^{ab}	6.93 ^a
12	6.84 ^b	7.19 ^a	6.98 ^a
16	6.93 ^a	7.13 ^a	6.91 ^a

a Least square means denoted by identical letters are not substantially different ($P \leq 0.05$) as determined by the Tukey–Kramer test.

Root Architecture Assessment

The results from pot experiment indicated that use of biochar led to a significant increase in several plant attributes, including root surface area, projected area, length, crossings, and fork numbers, can be ascribed to biochar's capacity to enhance soil physical and chemical characteristics. The porous structure of biochar and its elevated cation exchange capacity (CEC) improve soil aeration, water retention, and nutrient availability, hence fostering a more conducive environment for root development. Moreover, biochar can enhance advantageous microbial activity, facilitating plant growth and root development. The augmented root characteristics are likely attributable to the synergistic impacts of enhanced soil conditions, elevated nutrient availability, and advantageous microbial interactions, hence improving plant growth and productivity (Yousaf et al., 2025).

However, no distinction was noted between the groups with 0% and 4% biochar amendment. The 8%, 12%, and 16% biochar treatments did not demonstrate any statistically significant differences (Figure 1). The research demonstrated a significant increase in biomass, root volume, and arbuscular mycorrhizal colonization rate in corn following the application of wood-derived biochar (Infurna et al., 2023). The root growth enhancement could be achieved by improving soil physicochemical qualities. Previous studies have indicated that using biochar-based materials can potentially enhance root growth. Moreover, roots are capable of infiltrating the pores of biochar.



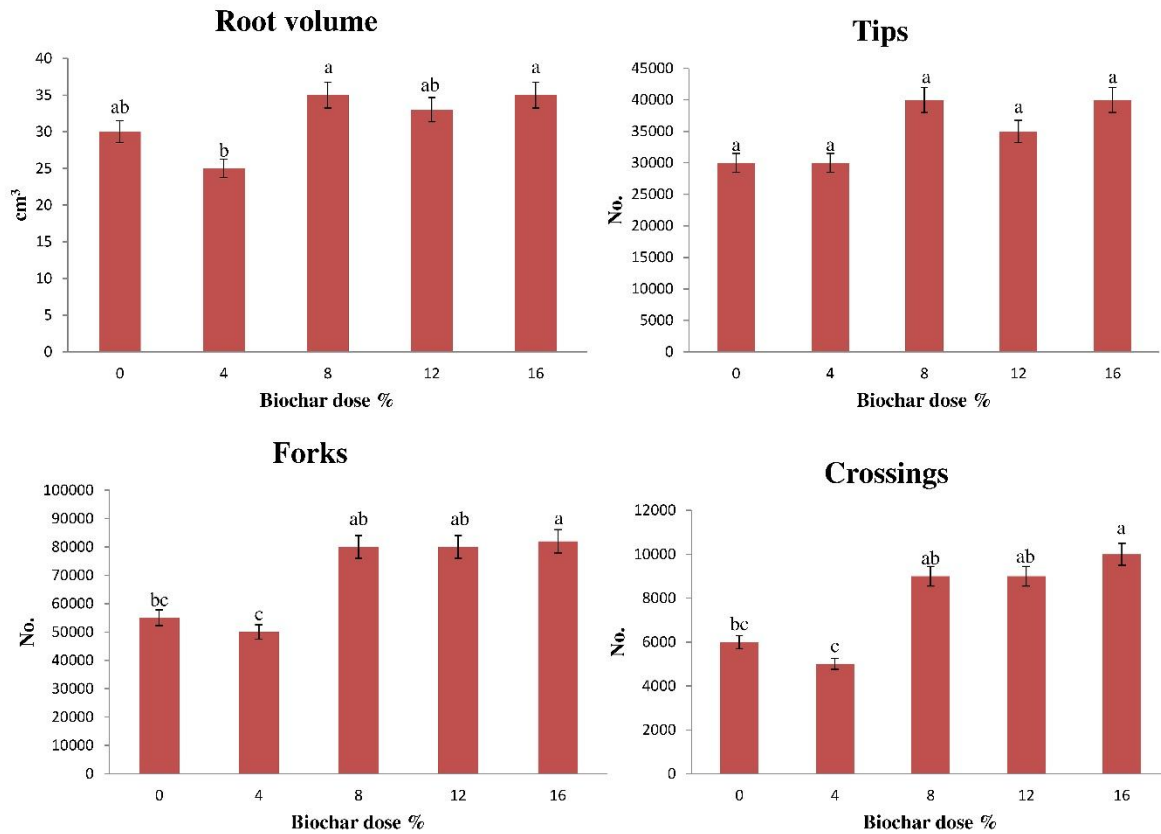


Figure 1

Root characteristics obtained from a pot study using the WinRhizo program. Bars with similar letters indicate no significant difference in least-squares means according to the Tukey–Kramer test ($P \leq 0.05$).

The fundamental properties of Moscatello, identified in the column study, are illustrated in Figure 2. No statistically significant variations were seen in project size, root volume, and surface area among the treatments. The average diameter, root length, number of crossings, forks, and root tips demonstrated a substantial increase following a 12% biochar treatment. The control group yielded the lowest values. Significantly, in the control sample, the root length had a similar surface area, albeit it possessed a more pronounced average diameter compared to the other treatments. The control group exhibited increased root thickness, while roots of Moscatello from various treatments displayed a finer texture. Alternatively referred to as feeder roots, fine roots serve as functional elements and play a crucial role in the acquisition of resources. Hence, the utilization of biochar has been found to facilitate the growth of feeder roots, consistent with the results of our experiments. The decrease in root diameter can be attributed to increased root occupancy of the soil pore space (Gaurav et al., 2025). The 12% biochar treatment resulted in the maximum number of root tips, higher root lengths, and a higher number of root crossings and forks. Nonetheless, no statistically significant difference in root size was seen across all other treatments. The treatments did not affect the root volume, surface area, or projected area. Soil mechanical resistance, encompassing bulk density, moisture content, and texture, is a primary factor affecting root growth. Sandy soil presents a considerable impediment to root development due to its low compressibility, inadequate structure, and high bulk density. Nevertheless, a certain number of these qualities might be counteracted by biochar improvement.

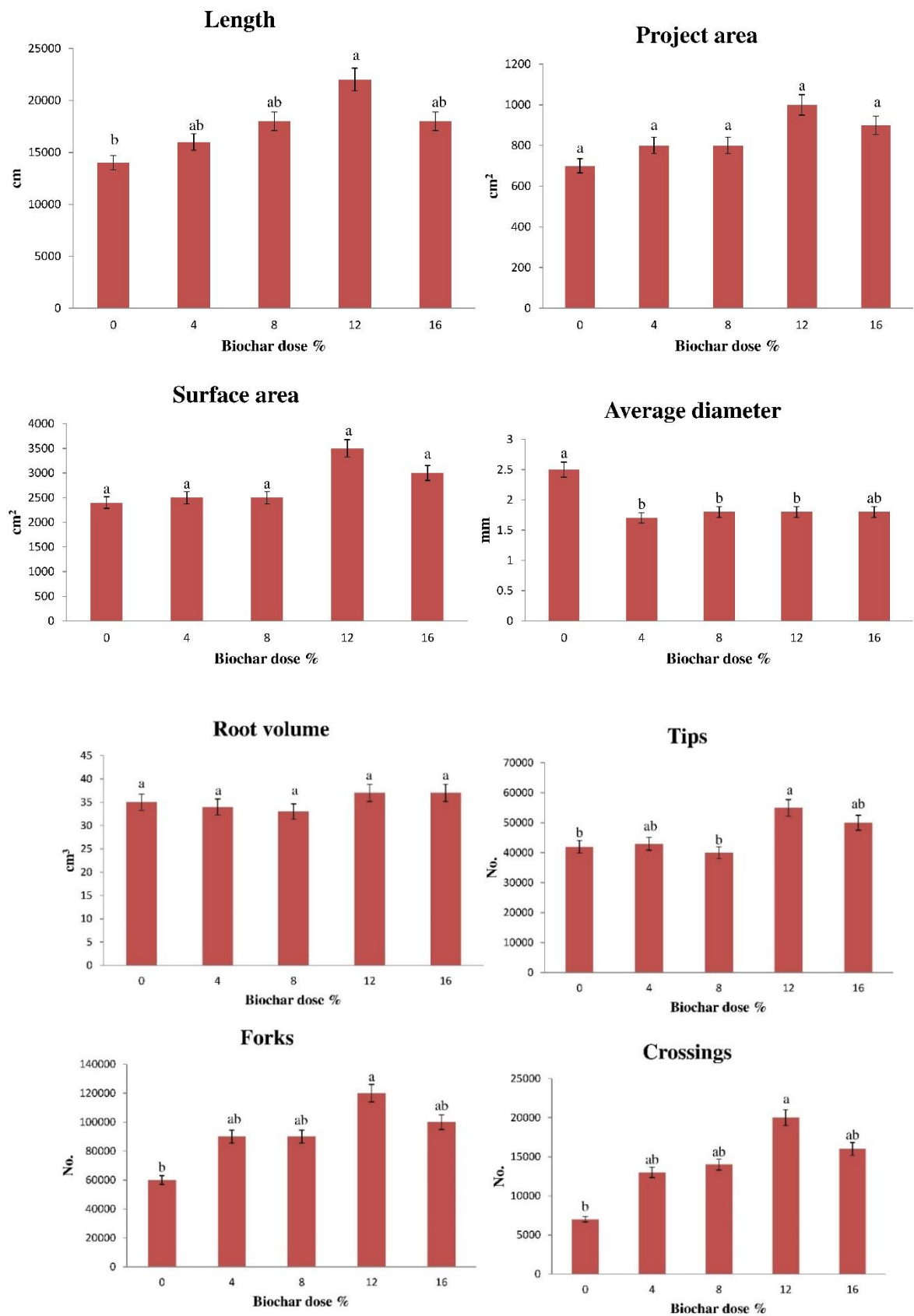


Figure 2

Characteristics of Moscatello plant taken from columns. The presence of bars with similar letters suggests that the least squares means do not exhibit a statistically significant difference ($P \leq 0.05$) as determined by the Tukey-Kramer test.

Conclusion

Biochar amendment markedly improved soil physical properties, including soil thermal regulation, bulk density, pH buffering, and water retention capacity. The reduction in bulk density enhanced soil aeration and porosity, creating better conditions for root growth. Biochar application also increased root length, root surface area, projected area, crossings, and forks. In contrast, plants grown without biochar showed shorter and thicker roots, suggesting that biochar promoted the formation of finer and more elongated roots. Therefore, if economically feasible, biochar can serve as an effective management strategy for Muscat grape cultivation, especially in sandy soils with low nutrient availability and poor water holding capacity. Acacia wood waste can also be converted into value-added biochar, improving soil quality and root architecture while supporting waste recycling and the circular economy. Further field studies are needed to evaluate biochars from different feedstocks, application rates, and crop growth stages.

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Author Contributions: G.M., M.U. designed and conceived the study idea. G.M. completed the experiments. R.I. analysed the data and performed visualizations and statistical data analysis. G.M., M.U. wrote the original draft. R.I. reviewed and edited the manuscript. All authors made valuable revisions and edited the manuscript and approved the last version.

Data Availability Statement: All the raw data in this research can be obtained from the corresponding authors upon reasonable request.

Permission

Permissions or Licenses were obtained to collect the Muscat grape variety known as "Moscatello", which has been extensively cultivated. The commercial nursery in Bahawalpur supplied tissue-cultured vines one month old. The department provided the biochar generated through the pyrolysis of *Acacia nilotica* before starting the research.

Ethics declarations

Ethics approval and consent to participate

This study does not include human or animal subjects.

Consent for publication

Not applicable.

Clinical trial number

Not applicable.

Statement on guidelines

All experimental studies and experimental materials involved in this research are in full compliance with relevant institutional, national and international guidelines and legislation.

Conflict of Interest

The authors stated that they had no interest which might be perceived as posing a conflict or bias. R.I. is an Editor of the journal. He was not involved in the editorial evaluation or publication decision concerning this manuscript.

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