Interactive Effects of Honeysuckle Planting and Biochar Amendment on Soil Structure and Hydraulic Properties of Hillslope Farmland

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Abstract: Plant roots and biochar amendment cause changes in soil structure and hydraulic properties; however, their interactive influences are still inadequately understood. A six-year field study was conducted on hillslope farmland in the Sichuan basin, China, to evaluate how honeysuckle planting and biochar application affect soil structure and hydraulic properties. Various parameters related to soil structure (soil organic matter (SOM), soil aggregate stability, bulk density were obtained in the laboratory) and hydraulic (hydraulic conductivity, soil water retention characteristics by single porosity of van Genuchten 1980 and dual porosity bi-exponential model) properties were determined. The results showed that honeysuckle planting alone increased (SOM) content, honeysuckle planting and biochar amendment jointly increased SOM content to a greater magnitude in top 20 cm soil but also markedly increase the SOM content in deeper soil layers (20–30 and 30–40 cm), while the application of biochar alone enhanced the SOM content in top 20 cm soil. The combination of honeysuckle planting and biochar amendment could increase soil aggregate stability. Furthermore, it was found that soil pores with size $r > 125 \, \mu m$ were the dominant macropores in all treatments. Honeysuckle planting increased saturated soil hydraulic conductivity ($K_s$) significantly ($p < 0.05$). Biochar amendment also significantly increased $K_s$ directly or indirectly through enhancement of SOM content. Results also showed that honeysuckle planting and biochar amendment could lead to a greater increase in saturated soil water content than saturated soil hydraulic conductivity. However, SOM showed lower value in bare land plots suggesting that both honeysuckle planting and biochar could increase SOM in soil, hence improving soil quality. Therefore, our field study demonstrated that the practice of honeysuckle planting and biochar amendment jointly in sloping farmland of purple soil could effectively strengthen soil structure and improve soil water retention.

Keywords: soil aggregate; macropores; saturated hydraulic conductivity; soil water retention curve; hillslope; purple soil

1. Introduction

Soil hydraulic properties are crucial for determining soil quality and environment, as well as its ability to serve the ecosystem [1]. Soil hydraulic properties, including water retention and hydraulic conductivity, are key parameters in studies of hydrological processes and the functioning of watersheds [2]. Plant roots are important in soil structure development for the formation of biopores from root growth and stabilization of soil aggregates [3], providing access to belowground water and nutrients [4–6], and anchoring plants in soils [7,8]. The roots of living plants alter the soil structure and hydrology parameters of the soil matrix (such as soil aggregate stability, soil cohesion, infiltration rate, soil moisture, and SOM) and reduce soil erosion [9]. Plant roots affect soil’s physical and hydraulic
properties in different ways, such as soil structure and pore system. For instance, plant roots can change soil hydraulic conductivities through macropores structure. According to Lu et al. [2], mature trees are characterized by coarse roots or decayed roots, which generate additional micropores and increase the heterogeneity of pore size distribution (PSD), leading to a decrease in $K_s$ as well as increased saturated water content. Germann et al. [10] reported that plant roots improve soil pore structure and form macropores that enhance infiltration, drainage, and aeration. Ni et al. [11] studied the effects of plant roots on the soil hydraulic properties under single species and mixed planting species, and their results showed that the planting of single species decreased $K_s$ while planting mixed species increased $K_s$. The inconsistent findings reflect that the current understanding of the impacts of plant roots on soil structure and soil hydraulic properties and underlying mechanisms is limited and insufficient.

Biochar is mostly used as a soil amendment to improve soil’s physical, chemical, and biological qualities and reduce soil erosion. Kammann et al. [12] found that co-composted biochars have a higher plant growth-promoting effect than biochar only in soil. Studies also found that adding biochar can increase hydraulic parameters and other soil physical properties such as water retention, plant available water capacity, bulk density, and porosity [13–15]. However, the influences of biochar may depend on soil type and region [16]. Generally, biochar amendment could improve soil water holding capacity due to two main reasons, biochar’s porous structure, which holds more water in biochar pores, and interaction of biochar with soil, which increases soil aggregates and hence improves soil water holding capacity [17].

Purple soil is an entisol based on the USDA soil classification and is a shallow, poorly structured soil formed by mudrocks or sandrocks. The soil is a very important arable soil type in the upper reaches of the Yangtze River watershed. Sloped farmland is the most common land type in this area. Purple soil on slopes is readily erodible and contains a large number of macropores, which contribute over 80% of the flow [14].

Honeysuckle, a perennial medical herb, is often planted for the purpose of soil and water conservation. In history, forestland and grassland in hilly purple soil areas of the upper Yangtze River watershed had been used for intensive agricultural activities and thus degraded. Since the 1970s, afforestation was implemented, mainly with cypress (alnus cremastogyne and cypress funebris), and led to improved soil quality, including changes in soil physical and hydraulic properties. To our best of knowledge, there is a scarcity of literature about the interactive effects of plant roots and biochar amendment on the physical and hydraulic properties of purple soil, and no studies were carried out to explore interactive effects of honeysuckle plant roots and biochar addition on the poor structure of purple soil.

Therefore, in this study, we conducted an experimental field study of honeysuckle planting and biochar addition in sloping farmland of purple soil, which is widely distributed in central hilly Sichuan in China and suffers severe water erosion.

We hypothesized that the honeysuckle planting and biochar addition in purple soil could alter soil structure, including both soil pore system and soil aggregate stability, and thus affect soil hydraulic properties. This study provides a better understanding of how honeysuckle planting and biochar amendment improves soil structure and water infiltration in soil and hence optimizes soil water management of purple soil.

2. Materials and Methods

2.1. Study Area

The research was carried out at the Agro-ecological station of purple soil in Yanting, which is located at 31°16’ N latitude and 105°27’ E longitude, in the hilly central Sichuan province of southwestern China (Figure 1a). The study area experiences a moderate subtropical monsoon climate, with an annual average temperature of 16.6 °C and annual
average precipitation of 846.4 mm [18], with 70% of rainfall mainly occurring during the rainy season (May to September) [19]. Sloping farmland is the most common land type in the catchment (44%), with an average slope of approximately 6°, and the typical soil in the catchment is readily erodible purple soil. The soil thickness on the slopes varies from 25 cm to 60 cm, and mudrock with visible fine fractures lies beneath the shallow purple soil and overlies impermeable sandstone [14]. The purple soil investigated in this research study is a loamy soil with a soil pH of 8.3, a bulk density of 1.33 g cm⁻³, SOM content of 8.75 g kg⁻¹, and Kₘ of 16.8 mm h⁻¹ [20].

Figure 1. (a) Location of the study area and (b) actual view of honeysuckle planting.

2.2. Soil Sampling

Soil samples were collected from long-term experimental plots (5 m in width and 20 m in length) with a slope of 6°. Four plots including (1) bare land plot (BL), (2) honeysuckle planting plot (HP), (3) bare land with 1% biochar applied to top 20 cm soil (BLBC), and (4) honeysuckle planting with 1% biochar applied to top 20 cm soil (HPBC) were selected for sampling. In HP and HPBC plots, both rhizosphere soil and inter-row soil were collected. These experimental plots were constructed in 2015 in farmland consolidated in 2013. The biochar applied in BLBC and HPBC plots is a commercial biochar made in China, from the pyrolysis of mixed straws, with organic matter content of 833.8 g kg⁻¹ and a pH of 10.22 [15]. A total of 1% (w/w, %) biochar was applied on the soil surface, followed by plowing to the depth of 20 cm. Honeysuckle (Figure 1b) was planted in the same year of 2015 after biochar application. Spacing in the rows of honeysuckle and spacing between rows was 80 cm, respectively. Since honeysuckle planting and biochar amendment in 2015, the plots have not been fertilized or tilled.

In BL and BLBC plots, undisturbed soil core samples (D = 5 cm, H = 5.05 cm) were collected from each plot at fourth depths of 0–10, 10–20, 20–30, and 30–40 cm with 3 replicates, and in HP and HPBC plots, soil core samples were collected from both rhizosphere soil and inter-row soil, respectively. Sampled soil cores were kept in a refrigerator at 4 °C before laboratory measurements of soil water retention curve, Kₛ and water content, bulk density, and porosity. Loose soil samples were also collected at each depth with the same sampling strategies as soil cores and were packed in plastic bags and transported to the laboratory for air drying. The air-dried loose soils were divided into two sub-samples. One sub-sample was kept in a plastic bag for soil aggregate size and stability analysis, another sub-sample was mashed and passed through a 2 mm mesh sieve for analysis of basic soil properties, including soil pH and SOM content.
2.3. Laboratory Analysis

2.3.1. Analysis of Soil Basic Properties

Soil pH was determined at a 1:5 soil-water ratio (w/v) by a pH meter [21]. Soil organic carbon (SOC) was measured by a CN analyzer. SOM content was obtained by multiplying 1.724 by the measured value of SOC [22]. Soil dry bulk density was measured by oven-drying at 105 °C for 24 h, and the porosity was obtained from bulk density (ρ_b) by considering a constant particle density of 2.65 g cm⁻³.

2.3.2. Soil Aggregate Size Distribution and Its Stability

The measurement and details of dry soil aggregate size distribution were determined by following the method used by [23,24]. Six aggregate size classes were determined by vernier caliper [24]; moreover, the aggregate size classes smaller than 1 mm (0.5–1 mm, 0.25–0.5 mm, and < 0.25 mm) and the mean particle size was obtained as the arithmetic mean of the upper and lower sieve sizes.

The mean weight diameter (MWD) was calculated as:

\[ MWD = \sum_{i=0}^{n} \bar{x}_i \times W_i \]  

where, \( \bar{x}_i \) is the mean diameter (mm) of aggregate at size \( i \); and \( W_i \) is the weight percentage (%) at size \( i \). The bigger the MWD value represents better soil aggregation and higher soil aggregate stability. A fractal dimension of mass, \( D_m \), quantifies space-filling characteristics of the solid in a space of radius \( r \). For a mass fractal, the scaling of mass, \( M \), follows a relationship of the form [25].

\[ M \sim r^{D_m}, \quad D_m \leq d \]  

where, \( d \) is the embedding dimension, defined as the minimum number of coordinates needed to enclose an object (i.e., \( d = 2 \) and \( d = 3 \) correspond to a two- and three-dimensional space, respectively). \( D_m \) can be obtained from measurements of mass on aggregates of different sizes. It can be estimated based on the Tyler and Wheatcraft (1992) model [26], which can be expressed as Equation (3):

\[ D_m = 3 - \frac{\log(W_i/W_0)}{\log(\bar{x}_i/\bar{x}_\text{max})} \]  

where, \( W_i \) is the mass of aggregates with size \(< d_i \); \( W_0 \) was the total mass of aggregates; \( \bar{x}_i \) was the mean aggregate diameter at a size class between \( d_i \) and \( d_{i+1} \), and, in this study, \( \bar{x}_i \) shared the same data with \( \bar{x}_i \) in Equation (1); \( \bar{x}_\text{max} \) was the mean diameter of aggregate at the top sieve (>10 mm class in this study).

2.3.3. Soil Hydraulic Properties

In the laboratory, soil core samples were saturated with distilled water from the bottom for 18 h, the saturated hydraulic conductivity (K_s) was measured using the constant head method [27]. After measurement of K_s, the soil water retention curve (SWRC) was measured on the same soil cores samples at 12 suctions of \(-1, -2.5, -10, -31.6, -63.1, 100, -337, -510, -1020, -2040, -5100, \) and \(-15300 \) cm H₂O. A sandbox-pressure plate was used for suctions of \(-1 \) to \(-100 \) cm H₂O, while the pressure plate was used at the suctions of \(-337 \) to \(-15300 \) cm H₂O (Soil Moisture Equipment Corp., Santa Barbara, CA, USA). At the end of the experiment, the soil cores were oven-dried at 105 °C for 24 h to determine soil water content.

The single porosity of van Genuchten (1980) model (vG) [28] and the dual porosity biexponential (BE) model [29] by the RETC fitting program (RECT Version 6.02, University of California) and the Origin software program (Origin Lab Corporation), respectively, were used to fit data of SWRC obtained.
The van Genuchten 1980 model equation can be described as:

\[ S^*(h) = \frac{\theta(h) - \theta_{r-vG}}{\theta_s-vG - \theta_{r-vG}} = \frac{1}{\left(1 + |\alpha_vG h|^n\right)^m} \]  

(4)

where, \( S^* \) is the relative water saturation of the soil, \( h \) is the pressure head (cm), \( \theta_{s-vG} \) and \( \theta_{r-vG} \) are the saturated water content and residual water content, respectively (m\(^3\) m\(^{-3}\)), and \( \alpha_vG \) (cm\(^{-1}\)), \( n \), and \( m (=1 - 1/n) \) are empirical parameters, \( n \) is related to slope of the SWRC at the inflection point [30].

The SWRC fitted using the vG model [28] has a unique inflection point where the curvature is zero or it changes from convex to concave. The water content at the inflection point (\( \theta_{inf} \)) of the fitted vG model [28] and the inflection slope (\( S_{inf} \)) were calculated from these model parameters using the equations from Dexter [31], as described as follow:

\[ \theta_{inf} = \theta_{r-vG} + (\theta_s-vG - \theta_{r-vG}) \left(1 + \frac{1}{m}\right)^{-m} \]  

(5)

\[ S_{inf} = -n(\theta_s-vG - \theta_{r-vG}) \left(1 + \frac{1}{m}\right)^{-(1+m)} \]  

(6)

The single porosity vG model [28] incorporates over the whole soil water retention curve to allow the determination of inflection slope (\( S_{inf} \)), which reflects the general soil physical quality.

The BE model can be described as:

\[ \theta = \theta_{r-BE} + \theta_{txt-BE} \exp \left(1 + \frac{h}{h_{a-txt}}\right) + \theta_{str-BE} \exp \left(1 + \frac{h}{h_{a-str}}\right) \]  

(7)

where, \( \theta_{txt-BE} \) represents the difference between saturated water content (\( \theta_{s-txt} \)) and the residual water content (\( \theta_{r-txt} \)) in the textural pore space; \( \theta_{str-BE} \) represents the difference between saturated water content (\( \theta_{s-str} \)) and residual water content (\( \theta_{r-str} \)) in the structural pore space; \( h_{a-txt} \) and \( h_{a-str} \) represent the air entry potentials in the textural and structural pore space, respectively; \( \theta_{r-BE} \) is the sum of residual soil water contents in the textural and structural pore space (\( =\theta_{r-txt}+\theta_{r-str} \)).

2.3.4. Characterization of Soil Pore System

The pore size distribution was determined as the derivative of the \( \theta(r) \) curve converted from the fitted vG and BE \( \theta(h) \) equations by calculating \( r (\mu m) \) (the radius of pores that remain full of water at a given pressure head (\( h \) (cm))) using the Young-Laplace equation [32]:

\[ r = \frac{1490}{|h|} \]  

(8)

According to the drainage capacity of the pore [14], the soil pore systems were categorized into 3 main classes (1) non-drainage micropores (<0.1 \( \mu m \) or \( |h| > 14900 \) cm, residual water), (2) drainable pores (0.1 < \( r < 125 \) \( \mu m \) or 12 cm < \( |h| < 14900 \) cm), and (3) gravitationally drainable macropores (\( r >125 \) \( \mu m \) or \( |h| < 12 \) cm).
2.4. Statistical Analysis

SPSS software (version 22, IBM SPSS Statistics) was used to analyze the data. Effects of honeysuckle plant roots and biochar on soil structure and hydraulic properties were examined by analysis of variance (ANOVA), while the interactive effect of honeysuckle planting and biochar amendment on soil was evaluated by multivariate analysis. Furthermore, using a generalized least squares estimator, a structural equation model (SEM) was used to analyze the impacts of the honeysuckle plant and biochar presence on SOM, soil structure (a latent variable including $S_{inf}$, MWD, and $D_m$), and soil hydraulic properties (saturated hydraulic conductivity, saturated soil water content, and soil residual water content), the relationships among SOM, soil structure, and soil hydraulic properties. The SEM was conducted using the `lavaan` package in R (R Core Team, 2020). All statistical tests were considered significant at $p < 0.05$. Origin Pro 9.1 (OriginLab, Northampton, MA, USA) was used for the generation of other plots.

3. Results

3.1. Soil Basic Properties

Soil basic properties are shown in Tables 1 and 2. For all plots, soil pH showed a sharp increase from 0–10 cm to 10–20 cm (from 8.26 to 8.36 in BL, from 8.17 to 8.35 in HP$_{rhi}$, from 8.31 to 8.36 in HP$_{int}$, and from 8.30 to 8.34 in HPBC$_{rhi}$, from 8.10 to 8.34 in HPBC$_{int}$). The 0–40 cm soil in plot BL showed a significantly higher average value of pH than that in plot HP ($p < 0.05$). The soil in plot HPBC showed a significantly lower soil pH than soil in plot BLBC. Soil organic matter (SOM) showed a significant difference with depth in BL and HP plots. Furthermore, planted location in plot HP (HP$_{rhi}$) showed a much higher SOM content compared to that at inter-row location (HP$_{int}$). Biochar amendment in soil caused a significantly higher SOM content in the top 20 cm compared to 20–40 cm. Moreover, HPBC$_{rhi}$ and HPBC$_{int}$ soil showed significantly higher SOM ($p < 0.05$) than soil in BLBC, indicating a strong accumulation of SOM by honeysuckle planting in purple soil.

Table 1. Soil pH, bulk density, total porosity, and SOM content in BL and HP plots.

| Plot   | Depth (cm) | pH          | Bulk Density (g cm$^{-3}$) | Porosity (m$^3$ m$^{-3}$) | SOM (g kg$^{-1}$) |
|--------|------------|-------------|----------------------------|---------------------------|-------------------|
| BL     | 0–10       | 8.26 ± 0.02a | 1.60 ± 0.08                | 0.39 ± 0.03               | 7.56 ± 0.65       |
|        | 10–20      | 8.36 ± 0.03ab| 1.59 ± 0.04                | 0.40 ± 0.02               | 4.75 ± 0.03       |
|        | 20–30      | 8.60 ± 0.18bc| 1.58 ± 0.08                | 0.40 ± 0.03               | 3.86 ± 0.31       |
|        | 30–40      | 8.68 ± 0.03c | 1.60 ± 0.06                | 0.39 ± 0.02               | 3.60 ± 0.18       |
|        | Mean       | 8.48 ± 0.19* | 1.59 ± 0.06                | 0.40 ± 0.02               | 4.94 ± 1.67*      |
| HP$_{rhi}$ | 0–10    | 8.17 ± 0.11a | 1.49 ± 0.02                | 0.43 ± 0.01               | 83.12 ± 6.91      |
|        | 10–20      | 8.35 ± 0.06ab| 1.58 ± 0.07                | 0.40 ± 0.03               | 89.28 ± 74.12     |
|        | 20–30      | 8.42 ± 0.07b | 1.54 ± 0.01                | 0.42 ± 0.00               | 79.24 ± 78.41     |
|        | 30–40      | 8.44 ± 0.01b | 1.65 ± 0.13                | 0.38 ± 0.05               | 67.28 ± 17.02     |
|        | Mean       | 8.35 ± 0.13* | 1.56 ± 0.09                | 0.41 ± 0.03               | 80.07 ± 55.69*    |
| HP$_{int}$   | 0–10     | 8.31 ± 0.02  | 1.55 ± 0.04                | 0.41 ± 0.02               | 55.26 ± 43.37     |
|        | 10–20      | 8.36 ± 0.04  | 1.61 ± 0.08                | 0.39 ± 0.03               | 39.35 ± 92.16     |
|        | 20–30      | 8.38 ± 0.09  | 1.44 ± 0.14                | 0.45 ± 0.05               | 23.27 ± 30.29     |
|        | 30–40      | 8.40 ± 0.03  | 1.59 ± 0.09                | 0.40 ± 0.03               | 74.27 ± 62.32     |
|        | Mean       | 8.36 ± 0.06* | 1.55 ± 0.10                | 0.42 ± 0.04               | 31.56 ± 50.14*    |

Note: SOM—soil organic matter content; BL—bare land treatment; HP$_{rhi}$—planted location in honeysuckle planting treatment; HP$_{int}$—inter-row location in honeysuckle planting treatment; different lower case letters represent significant differences at the 0.05 level among soil depths in each plot; * means significant differences ($p < 0.05$) in mean value among treatments at 0–40 cm depth.
Table 2. Soil pH, bulk density, total porosity, and SOM content in plots BLBC and HPBC.

| Soil    | Depth (cm) | pH      | Bulk Density (g cm⁻³) | Porosity (m³ m⁻³) | SOM (g kg⁻¹) |
|---------|------------|---------|-----------------------|-------------------|--------------|
|         |            |         |                       |                   |              |
| BLBC    | 0–10       | 8.30 ± 0.02a | 1.55 ± 0.04             | 0.41 ± 0.02      | 62.81 ± 13.68 |
|         | 10–20      | 8.36 ± 0.04c | 1.60 ± 0.08             | 0.39 ± 0.03      | 14.19 ± 1.04  |
|         | 20–30      | 8.38 ± 0.09b | 1.44 ± 0.14             | 0.45 ± 0.05      | 6.20 ± 0.36   |
|         | 30–40      | 8.40 ± 0.03c | 1.59 ± 0.09             | 0.40 ± 0.03      | 5.96 ± 0.96   |
|         | Mean       | 8.36 ± 0.06 * | 1.55 ± 0.10 *          | 0.41 ± 0.04 *    | 22.29 ± 25.37 * |
| HPBCrhi | 0–10       | 8.10 ± 0.12a | 1.39 ± 0.15             | 0.47 ± 0.05      | 111.56 ± 111.5 |
|         | 10–20      | 8.34 ± 0.06b | 1.58 ± 0.07             | 0.40 ± 0.03      | 111.8 ± 93.25 |
|         | 20–30      | 8.34 ± 0.02b | 1.65 ± 0.04             | 0.37 ± 0.02      | 75.50 ± 27.03 |
|         | 30–40      | 8.31 ± 0.09ab| 1.58 ± 0.14             | 0.40 ± 0.05      | 70.42 ± 54.53 |
|         | Mean       | 8.27 ± 0.13 * | 1.55 ± 0.14 *          | 0.41 ± 0.05 *    | 94.27 ± 70.79 * |
| HPBCint | 0–10       | 8.18 ± 0.09 | 1.48 ± 0.06             | 0.44 ± 0.02a     | 55.11 ± 15.66 |
|         | 10–20      | 8.33 ± 0.09 | 1.53 ± 0.07             | 0.42 ± 0.03a     | 42.34 ± 55.26 |
|         | 20–30      | 8.35 ± 0.10 | 1.52 ± 0.03             | 0.42 ± 0.01a     | 33.1 ± 7.35   |
|         | 30–40      | 8.30 ± 0.11 | 1.46 ± 0.10             | 0.45 ± 0.04 *    | 52.56 ± 31.12 |
|         | Mean       | 8.30 ± 0.11 | 1.46 ± 0.10             | 0.45 ± 0.04 *    | 52.56 ± 31.12 |

Note: SOM—soil organic matter; HPBCrhi—planted location in honeysuckle planting plus biochar addition plot; HPBCint—inter-row location in honeysuckle planting plus biochar addition plot; different lower case letters represent significant differences at the 0.05 level among soil depths in each plot; * means significant differences of mean value among plots at 0–40 cm depth.

3.2. Soil Aggregate Size Distribution and Its Stability

Measurements of soil dry aggregate size distribution (represented by MWD) and aggregate stability (represented by Dm) are presented in Figure 2. It was found that MWD exhibited no changes with depth in all plots except plot BLBC. Compared to the other treatments, plot BLBC showed significantly higher MWD at 0–10 cm and 10–20 cm but lower MWD at depths of 20–30 cm and 30–40 cm.

At a depth of 0–10 cm, the soil in plot BLBC showed the highest Dm, indicating better aggregate stability. There were no significant differences in Dm among different soil layers (p > 0.05) for all plots. Two-way ANOVA analysis found that honeysuckle roots or biochar amendment individually had no significant influence on Dm (p > 0.05); however,
the interaction of honeysuckle root with biochar amendment caused a significant increase of \( D_m \)\(^{(p = 0.04)}\).

3.3. Soil Water Retention Curve (SWRC) Estimated by \( vG \) and \( BE \) Models

Soil water retention curves of studied plots were shown in Figures 3 and 4. The residual water content \( (\theta_r) \) ranged from 0.18 m\(^3\) m\(^{-3}\) to 0.30 m\(^3\) m\(^{-3}\) with an averaged value of 0.24 m\(^3\) m\(^{-3}\), and saturated water content \( (\theta_s) \) ranged from 0.35 m\(^3\) m\(^{-3}\) to 0.58 m\(^3\) m\(^{-3}\) with an averaged value of 0.43 m\(^3\) m\(^{-3}\) (Tables 3 and 4). Plot BLBC showed significantly higher \( \theta_r \) compared to plot BL. Rhizospheric soil at 0–10 cm and 10–20 cm in plot HP \( (HP_{rhi}) \) showed higher \( \theta_s \) than the soil at plot HP’s inter-row location \( (HP_{int}) \) and the soil in plot BL, and rhizospheric soil in plot HPBC \( (HPBC_{rhi}) \) also had higher \( \theta_s \) than the soil at plot HPBC’s inter-row location \( (HPBC_{int}) \) and the soil in plot BLBC, indicating an increase of soil water capacity by honeysuckle planting.

![Figure 3](image-url)

**Figure 3.** Comparison of soil water retention curves obtained by fitting the single porosity van Genuchten (1980) model (SWRC\(vG\)) and biexponential model (SWRC\(BE\)) to water content data measured on soil core samples collected from plot BL, inter-row location \( (HP_{int}) \), and honeysuckle planted location \( (HP_{rhi}) \) of plot HP.
Figure 4. Comparison of the soil water retention curves obtained by fitting the single porosity van Genuchten (1980) model (SWRC-vG) and biexponential model (SWRC-BE) to water retention data measured on soil core samples collected from plot BLBC, inter-row location (HPBC int), and honeysuckle planted location (HPBCrhi) of plot HPBC.

Table 3. Fitted soil water retention parameters (mean ± std.) by using vG and BE model in plots BL and HP.

| Soil    | Depth (cm) | vG Model | BE Model | vG Model | BE Model | vG Model | BE Model |
|---------|------------|----------|----------|----------|----------|----------|----------|
|         |            | \( \theta_r \) | \( \theta_s \) | \( n \) | \( s_{\inf} \) | \( \theta_{r-BE} \) | \( \theta_{s-BE} \) | \( \theta_{r-BE} \) |
| BL      | 0–10       | 0.230 ± 0.025 | 0.421 ± 0.034 | 1.21 ± 0.08 | 0.035 ± 0.002 | 0.238 ± 0.034 | 0.102 ± 0.041 | 0.147 ± 0.015 |
|         | 10–20      | 0.232 ± 0.016 | 0.435 ± 0.019 | 1.14 ± 0.04 | 0.034 ± 0.002 | 0.235 ± 0.028 | 0.108 ± 0.029 | 0.117 ± 0.014 |
|         | 20–30      | 0.199 ± 0.009 | 0.398 ± 0.028 | 1.20 ± 0.03 | 0.026 ± 0.005 | 0.207 ± 0.038 | 0.102 ± 0.008 | 0.070 ± 0.007 |
|         | 30–40      | 0.210 ± 0.012 | 0.430 ± 0.015 | 1.19 ± 0.09 | 0.022 ± 0.008 | 0.218 ± 0.029 | 0.112 ± 0.039 | 0.091 ± 0.006 |
| HP_{rhi}| 0–10       | 0.240 ± 0.038 | 0.445 ± 0.014 | 1.26 ± 0.08 | 0.046 ± 0.004 | 0.243 ± 0.037 | 0.086 ± 0.006 | 0.117 ± 0.037 |
|         | 10–20      | 0.253 ± 0.015 | 0.436 ± 0.026 | 1.26 ± 0.06 | 0.034 ± 0.006 | 0.256 ± 0.016 | 0.103 ± 0.034 | 0.086 ± 0.012 |
|         | 20–30      | 0.238 ± 0.022 | 0.407 ± 0.007 | 1.12 ± 0.05 | 0.023 ± 0.005 | 0.239 ± 0.025 | 0.090 ± 0.018 | 0.082 ± 0.013 |
|         | 30–40      | 0.227 ± 0.013 | 0.385 ± 0.032 | 1.16 ± 0.08 | 0.024 ± 0.010 | 0.230 ± 0.014 | 0.067 ± 0.026 | 0.088 ± 0.017 |
| HP_{int}| 0–10       | 0.227 ± 0.017 | 0.423 ± 0.012 | 1.23 ± 0.11 | 0.037 ± 0.012 | 0.232 ± 0.015 | 0.097 ± 0.019 | 0.103 ± 0.026 |
|         | 10–20      | 0.213 ± 0.012 | 0.412 ± 0.014 | 1.22 ± 0.07 | 0.034 ± 0.005 | 0.222 ± 0.011 | 0.105 ± 0.015 | 0.093 ± 0.011 |
|         | 20–30      | 0.236 ± 0.018 | 0.429 ± 0.021 | 1.20 ± 0.04 | 0.027 ± 0.001 | 0.241 ± 0.017 | 0.105 ± 0.009 | 0.091 ± 0.011 |
|         | 30–40      | 0.218 ± 0.015 | 0.400 ± 0.027 | 1.09 ± 0.02 | 0.021 ± 0.005 | 0.222 ± 0.013 | 0.084 ± 0.026 | 0.095 ± 0.016 |
Rhizospheric soil (HP\(_{\text{rhi}}\)) at the top 20 cm showed the highest \(\theta_{r-BE}\) compared to the inter-row soil and the soil in bare land (Table 3). HPBC\(_{\text{int}}\) and HPBC\(_{\text{rhi}}\) soil showed higher \(\theta_{r-BE}\) at depths of 0–10 cm and 10–20 cm than that in the BLBC plot (Table 4). However, drainable soil textural porosity (\(\theta_{\text{str-BE}}\)) showed the opposite pattern: bare land soil at the top 20 cm had the highest value while rhizospheric soil at the top 20 cm had the lowest value. The drainable structural porosity (\(\theta_{\text{str-BE}}\)) of the top 20 cm soil showed the same pattern as \(\theta_{\text{str-BE}}\), indicating a decrease of drainable soil porosity by honeysuckle planting.

The parameter \(n\) of vG model [28] is mostly related to soil texture rather than soil structure, and \(n\) is positively related to \(S_{\text{inf}}\), which is an indicator of the soil physical quality. Dexter [35] proposed that the \(S_{\text{inf}}\) of soil water retention curve can be used as an index of soil quality because it reflects microstructural porosity. The values of inflection slope (\(S_{\text{inf}}\)) at a depth of 0–10 cm for different plots were relatively higher than other soil layers and followed the order, HP\(_{\text{rhi}}\) (0.046) > HP\(_{\text{int}}\) (0.037) > BL (0.035), which could reflect the marked impacts of plant roots on soil physical quality. Across soil profiles, lower \(S_{\text{inf}}\) values were observed at depths of 20–30 cm and 30–40 cm in both plot BL and plot HP. Higher \(S_{\text{inf}}\) values of shallow soil layers in plot HPBC than plot HP were found, which could be attributed to biochar amendment in soil. Comparison of plots BL and BLBC revealed that the treatment of biochar addition alone could have a significant positive influence on \(S_{\text{inf}}\) of unplanted soil (\(p = 0.005\)).

Different values of \(S_{\text{inf}}\) were proposed as an indication of good and poor soil pore systems. For example, Dexter and Czyz [34] proposed a \(S_{\text{inf}}\) value of 0.035 as the dividing line between soils with good and poor structural quality. However, Andrade and Stone [35] suggested that the \(S_{\text{inf}}\) value of 0.045 can be used to measure the soils with good structure conditions from degraded soils, while values of \(S_{\text{inf}} \leq 0.025\) represent degrading soil physical state. As shown in Tables 3 and 4, the observed higher \(S_{\text{inf}}\) values of HP compared to bare land indicate a better soil structure developed by honeysuckle planting, and the higher \(S_{\text{inf}}\) values in plot HPBC (with an average value of 0.041) than plot HP (with an average value of 0.031) reflect a further positive contribution of biochar amendment on soil physical quality.

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Table 4. Fitted soil water retention parameters (mean ± std.) by using vG and BE model in plots BLBC and HPBC.

| Soil    | Depth (cm) | \(\theta_{i}\) (m\(^3\) m\(^{-3}\)) | \(\theta_{r}\) (m\(^3\) m\(^{-3}\)) | \(n\) | \(S_{\text{inf}}\) | \(\theta_{\text{BE}}\) (m\(^3\) m\(^{-3}\)) | \(\theta_{\text{str-BE}}\) (m\(^3\) m\(^{-3}\)) | \(\theta_{\text{tot-BE}}\) (m\(^3\) m\(^{-3}\)) |
|---------|------------|----------------------------|----------------------------|------|----------------|----------------|----------------|----------------|
| BL      | 0–10       | 0.290 ± 0.025              | 0.506 ± 0.035              | 1.51 ± 0.05 | 0.060 ± 0.015 | 0.183 ± 0.034 | 0.201 ± 0.071 | 0.148 ± 0.012 |
|         | 10–20      | 0.256 ± 0.019              | 0.436 ± 0.044              | 1.09 ± 0.09 | 0.027 ± 0.004 | 0.193 ± 0.039 | 0.146 ± 0.051 | 0.117 ± 0.014 |
|         | 20–30      | 0.255 ± 0.011              | 0.432 ± 0.021              | 1.33 ± 0.11 | 0.034 ± 0.008 | 0.261 ± 0.025 | 0.110 ± 0.049 | 0.070 ± 0.004 |
|         | 30–40      | 0.235 ± 0.009              | 0.418 ± 0.051              | 1.18 ± 0.08 | 0.029 ± 0.005 | 0.243 ± 0.021 | 0.091 ± 0.012 | 0.092 ± 0.005 |
|         | 0–10       | 0.288 ± 0.018              | 0.534 ± 0.045              | 1.26 ± 0.07 | 0.056 ± 0.012 | 0.256 ± 0.049 | 0.177 ± 0.088 | 0.107 ± 0.020 |
| HPBC\(_{\text{rhi}}\) | 10–20      | 0.233 ± 0.046              | 0.459 ± 0.033              | 1.19 ± 0.01 | 0.040 ± 0.004 | 0.220 ± 0.018 | 0.136 ± 0.069 | 0.110 ± 0.015 |
|         | 20–30      | 0.232 ± 0.024              | 0.428 ± 0.045              | 1.20 ± 0.06 | 0.038 ± 0.007 | 0.234 ± 0.024 | 0.100 ± 0.072 | 0.096 ± 0.027 |
|         | 30–40      | 0.257 ± 0.016              | 0.415 ± 0.018              | 1.23 ± 0.11 | 0.044 ± 0.015 | 0.250 ± 0.022 | 0.088 ± 0.050 | 0.079 ± 0.014 |
|         | 0–10       | 0.272 ± 0.034              | 0.502 ± 0.026              | 1.28 ± 0.07 | 0.047 ± 0.012 | 0.279 ± 0.034 | 0.148 ± 0.016 | 0.079 ± 0.007 |
| HPBC\(_{\text{int}}\) | 10–20      | 0.232 ± 0.043              | 0.440 ± 0.011              | 1.23 ± 0.06 | 0.039 ± 0.002 | 0.233 ± 0.039 | 0.137 ± 0.031 | 0.075 ± 0.018 |
|         | 20–30      | 0.213 ± 0.016              | 0.418 ± 0.030              | 1.18 ± 0.03 | 0.036 ± 0.007 | 0.218 ± 0.016 | 0.117 ± 0.015 | 0.087 ± 0.003 |
|         | 30–40      | 0.231 ± 0.010              | 0.405 ± 0.010              | 1.16 ± 0.04 | 0.026 ± 0.005 | 0.233 ± 0.008 | 0.097 ± 0.015 | 0.073 ± 0.002 |
3.4. Soil Pore Distribution Estimated by SWRC

Analysis of characteristics of 3 pore size classes (i.e., \( r > 125 \mu m \), \( 0.1 < r < 125 \mu m \) and \( r < 0.1 \mu m \)) showed that pores with size \( r > 125 \mu m \) were dominant in the studied soil. At depth of 0–10 cm, relative percentage of pores with size \( r > 125\mu m \) was higher in plots with biochar amendment (plots BLBC and HPBC) \(( p < 0.05 \)) at a depth of 10–20 cm, the highest relative percentage of pores with size \( r > 125 \mu m \) were observed in plot BLBC. Furthermore, at a depth of 10–20 cm, the difference in relative percentage of pores with \( r > 125 \mu m \) between HPBC and HP plot was smaller than their differences at a depth of 0–10 cm. At a depth of 20–30 cm, the gap is further narrowed for the relative percentage of pores with size \( r > 125 \mu m \). However, when it comes to soil at a depth of 30–40 cm, all of the 3 pore size groups showed significant differences among plots \(( p < 0.05 \)). HP_rhi and HP_int showed lower relative percentages of soil pores with size \( r > 125 \mu m \), compared to BL. Contrastingly, HPBC_rhi and HPBC_int showed a higher relative percentage of pores with size \( r > 125 \mu m \), compared to BLBC.

3.5. Saturated Soil Hydraulic Conductivity

Statistical analysis revealed that there are significant differences in \( K_s \) among all plots \(( p = 0.005 \)). HP_rhi and HP_int topsoil showed higher \( K_s \) compared to BL, indicating an improvement of saturated water conductivity by honeysuckle planting (Figure 5a). Comparing \( K_s \) values between the topsoils of plots BLBC and HPBC (Figure 5b), it was found that honeysuckle planting could lead to a greater increase of saturated water conductivity in biochar amended soil \(( p = 0.000 \)).

Figure 5. (a) Mean values and standard deviations of saturated soil hydraulic conductivity \(( K_s \)) for BL, HP_rhi and HP_int; (b) Mean values and standard deviations of saturated soil hydraulic conductivity \(( K_s \)) for BLBC, HPBC_rhi and HPBC_int. Note: BL—bare land treatment; HP_rhi—planted location in honeysuckle planting treatment; HP_int—inter-row location in honeysuckle planting treatment; BLBC—bare land with biochar; HPBC_rhi—planted location in honeysuckle planting plus biochar addition plot; HPBC_int—inter-row location in honeysuckle planting plus biochar addition plot.
3.6. Linking Treatment with Soil Properties

Soil bulk density was negatively correlated with relative percentages of pores with size \( r > 125 \, \mu m \), \( \theta_{r-BE} \) and \( \theta_{txt-BE} \). Soil pH was negatively correlated with relative percentages of pores with size \( r > 125 \, \mu m \) and \( \theta_{r-BE} \), and positively correlated with relative percentages of pores with size \( r < 0.1 \, \mu m \). No relationships of soil organic matter content with soil pore characteristics were observed (Table 5).

### Table 5. Correlations of basic soil properties with soil pore characteristics at 0–40 cm soil for all studied plots.

| Soil Basic Properties | \( r > 125 \) (\( \mu m \)) | \( 0.1 < r < 125 \) (\( \mu m \)) | \( r < 0.1 \) (\( \mu m \)) | \( \theta_{r-BE} \) (\( m^3 \cdot m^{-3} \)) | \( \theta_{txt-BE} \) (\( m^3 \cdot m^{-3} \)) | \( \theta_{str-BE} \) (\( m^3 \cdot m^{-3} \)) | Total Porosity % |
|-----------------------|-----------------------------|-------------------------------|-----------------------------|---------------------------------|---------------------------------|---------------------------------|-----------------|
| Bulk density          | \(-0.461 \) **             | \(-0.068 \)                   | \(0.224 \)                  | \(-0.299 \) *                    | \(-0.402 \) **                  | \(0.092 \)                   | \(-1.000 \) ** |
| pH                    | \(-0.301 \) *              | \(-0.246 \)                   | \(0.324 \) *                | \(-0.273 \) *                    | \(-0.239 \)                    | \(0.027 \)                   | \(-0.275 \) *   |
| SOM                   | \(0.053 \)                 | \(0.119 \)                    | \(-0.123 \)                 | \(-0.085 \)                      | \(-0.074 \)                    | \(0.209 \)                   | \(-0.017 \)     |

* means significance at 0.05 level, and ** means significance at 0.01 level.

Results of two-way ANOVA analysis of the interaction between honeysuckle plant roots and biochar amendment on soil pore characteristics are presented in Table 6. Honeysuckle planting only caused a significant influence on pores with size \( r < 0.1 \, \mu m \), while biochar amendment caused significant influences on pores with size \( r > 125 \, \mu m \) and \( r < 0.1 \, \mu m \). Interaction of honeysuckle planting and biochar addition caused significant changes in relative percentages of pores with size \( r < 0.1 \, \mu m \) and \( 0.1 \, \mu m < r < 125 \, \mu m \).

### Table 6. P values of the interaction between honeysuckle planting and biochar amendment on soil pores estimated by SWRC.

| Treatment                  | \( r < 0.1 \, \mu m \) | \( 0.1 \, \mu m < r < 125 \, \mu m \) | \( r > 125 \, \mu m \) |
|----------------------------|------------------------|------------------------------------|------------------------|
| Honeysuckle planting       | 0.049                  | 0.177                              | 0.168                  |
| Biochar amendment          | 0.001                  | 0.053                              | 0.000                  |
| Honeysuckle planting × Biochar | 0.004                | 0.009                              | 0.112                  |

3.7. SEM

SEM analysis found honeysuckle planting was positively correlated to the latent variable “soil structure” (Figure 6, \( R^2 = 0.35, p < 0.05 \)), but the relationships of honeysuckle planting with \( K_s \), \( \theta_r \) and \( \theta_s \) were not significant \((p > 0.05)\). Biochar amendment showed positive relationships with “soil structure” \((R^2 = 0.45, p < 0.05)\), saturated soil water conductivity \( K_s \) \((R^2 = 0.48, p < 0.05)\), and saturated water content \((R^2 = 0.31, p < 0.05)\), while biochar amendment exhibited no significant relationships with soil residual water content \((p > 0.05)\). A better “soil structure” could lead to a higher \( \theta_r \) but a lower \( \theta_s \) \((p < 0.05)\). SOM content had a strong positive relationship with soil residual water content; however, there was no significant relationship between SOM content with \( K_s \) \((p > 0.05)\) and \( \theta_s \) \((p > 0.05)\). A higher SOM content may be associated with a better “soil structure”, but this positive bidirectional relationship was not statistically significant \((R^2 = 0.09, p > 0.05)\).
Honeysuckle planting decreased soil pH and showed higher SOM in plot HP, as compared to the soil in bare land (Table 1). This implied that honeysuckle plant roots affected the soil properties of the HP plot. The decrease in soil pH indicated the function of honeysuckle planting to neutralize the alkalinity of purple soil in this studied area. Previous studies in soils with similar genesis reported a decrease of soil pH by frequent cultivation in sloping low land [24]. The observed higher SOM in plot HP, which indicates the enrichment of SOM by planting through leaf litter return to soil, might be one mechanism of soil neutralization by planting [36]. With honeysuckle planting, root exudate and soil microbial activities inspired by soil organic matter would be another mechanism of soil neutralization [37,38].

Honeysuckle planting improved soil structure and water retention of the purple soil (Table 3). The observed higher value of $S_{\text{inf}}$ in HP$_\text{rhi}$ than bare land indicates a better soil physical quality as a result of the growth of honeysuckle roots. These results implied that honeysuckle roots altered the poor structure of purple soil in the studied area. Furthermore, honeysuckle planting improved the saturated soil hydraulic conductivity, as compared to bare land (Figure 7a). The root development of honeysuckle changed the pore system through the mechanical moving of soil particles and aggregates [37], which is crucial in macropore formation. The formation of soil macro pores can change soil structure and hydraulic conductivity and thus lead to greater water infiltration in the soil. Our results are consistent with Luo et al. [39], who reported that plant roots increased the saturated hydraulic conductivity of soil covers in a four-year field experiment in South China. Meanwhile, the decreased soil organic matter by litter leaf and rhizospheric decomposition of the honeysuckle roots could improve soil water retention and water-stable aggregates, which is in agreement with the results of a previous study with other perennial plants [40]. Our results suggest that honeysuckle planting could be considered as a measure to improve soil hydraulic properties and optimize the water management in sloping farmland of this purple soil area, which is prone to drought stress [14,41].

**4. Discussion**

**4.1. Effects of Honeysuckle Planting**

![Figure 6. Results of SEM path analysis. Arrows represent the directionality of influence, with negative relationships represented by a dashed line. Black indicates a significant relationship ($p < 0.05$) and grey represents an insignificant relationship ($p > 0.05$). Thicker lines represent stronger correlations. Note: SOM—soil organic matter; $K_s$—saturated soil hydraulic conductivity; $\theta_s$—saturated water content; $\theta_r$—residual water content.](image-url)
Biochar treatment can improve soil structure by increasing soil porosity. For example, Blanco-Canqui et al. [47] observed that biochar increased the percentage of porosity by 14% to 64%, implying that the addition of biochar in soil improved soil structure.

Biochar amendment could also enhance soil water retention (Figure 7) due to biochar’s larger amount of pores and specific surface area, which might result in an increase in the content of available water in soil [46]. Our findings are similar to that of Wong et al. [54], who reported that biochar addition increased the saturated hydraulic conductivity of kaolin clay. On the contrary, Ni et al. [55] reported that biochar decreased saturated hydraulic conductivity in a two-year field study. Biochar effects are strongly dependent on soil type [46], and the differences in the type of feedstock and pyrolysis temperature could also partly explain the inconsistent results obtained in different studies.

4.3. Interactive Effects of Planting and Biochar

In our study, the neutralization effect of honeysuckle planting combined with biochar addition was observed in the alkaline purple soil. Honeysuckle plants improved the SOM of the studied area; these results implied the improvement of purple soil structure.

Figure 7. Relative percentages of three pore size groups calculated from SWRC for each soil layer in experimental plots. Note: BL—bare land treatment; HPrhi—planted location in honeysuckle planting treatment; HPint—inter-row location in honeysuckle planting treatment; BLBC—bare land with biochar; HPBCrhi—planted location in honeysuckle planting plus biochar addition plot; HPBCint—inter-row location in honeysuckle planting plus biochar addition plot.

4.2. Effects of Biochar Amendment

The application of biochar increased SOM content and reduced soil bulk density (Table 2). This implied that biochar improved the soil structure of purple soil with high organic matter and high soil porosity of the studied area. Biochar is a carbon-rich, porous material produced from different biomass products such as plants, animals, and sewage in a limited oxygen environment [42–44] and is widely known as a potential soil amendment to improve soil quality [45,46]. Thus, the addition of biochar in the soil directly increases soil porosity and reduces bulk density [47] due to the higher porosity and lower bulk density of biochar than soil [48]. Alternatively, the much higher carbon content of biochar than soil (about 83%) is responsible for the observed increases in SOM content upon biochar amendment. Our results conform to the previous study’s findings of [46,48–52]. Moreover, biochar amendment improved soil structure. First, biochar increased the content of macropores in the purple soil, in particular, that of pores $r > 125 \, \mu m$ (Figure 5). A previous study on shallow entisol [17] found that biochar increased mesoporosity and decreased macroporosity of soil. Secondly, biochar increased soil physical quality, as indicated by a higher value of $S_{inf}$ (Table 4). The results are consistent with Liu et al. [15], who reported an increase in $S_{inf}$ index of purple soil under cropping rotations of winter wheat and summer maize by biochar treatment. Generally, biochar has a highly porous structure with higher porosity and larger surface area than soil [53], and biochar application could increase soil porosity as well as soil structure. For example, Blanco-Canqui et al. [47] observed that biochar increased the percentage of porosity by 14% to 64%, implying that the addition of biochar in soil improved soil structure.
Biochar amendment could also enhance soil water retention (Figure 7) due to biochar’s larger amount of pores and specific surface area, which might result in an increase in the content of available water in soil [46]. Our findings are similar to that of Wong et al. [54], who reported that biochar addition increased the saturated hydraulic conductivity of kaolin clay. On the contrary, Ni et al. [55] reported that biochar decreased saturated hydraulic conductivity in a two-year field study. Biochar effects are strongly dependent on soil type [46], and the differences in the type of feedstock and pyrolysis temperature could also partly explain the inconsistent results obtained in different studies.

4.3. Interactive Effects of Planting and Biochar

In our study, the neutralization effect of honeysuckle planting combined with biochar addition was observed in the alkaline purple soil. Honeysuckle plants improved the SOM of the studied area; these results implied the improvement of purple soil structure and hydraulic properties. The SOM increase was a result of inputs from aboveground litter, root decay, and rhizo-decomposition [56]. Biochar application in soil with organic matter from plants could catalyze the oxidation of biochar and may form acidic organic matter [57], further producing acidic matter [58,59]. The formation of acidic organic functional groups in the soil can neutralize the alkalinity of the soil. A mesocosm study by Ntacyabukura et al. [44] reported that biochar increased soil pH in Eutric regosols called purple soil, which is inconsistent with the results of our present study. Apparently, this difference is due to honeysuckle planting, which neutralized not only the alkaline purple soil but also the alkaline (pH 10.22) biochar amended in our study.

Honeysuckle planting after biochar application can facilitate the relocation of biochar to the deep soil layers depth through root growth (to a depth of 40 cm). Therefore, the presence of roots together with the relocated biochar in the deep layers may be responsible for the observed increases in SOM content. The increased SOM would accelerate soil microbial activity and further improve soil aggregate stability and soil physical quality [60,61]. A previous study by Wang et al. [62] reported that biochar alone could improve soil structure as well as soil aggregate stability in Yolo soil. Our findings suggest that implementation of both honeysuckle planting and biochar addition in purple soil can increase the SOM and moreover enhance the soil quality in hilly areas of the Sichuan basin.

A previous study by Wang et al. [14] reported that macropores contributed more than 87.9% to water flow in the shallow entisol. All changes of soil structure induced by planting and biochar amendment would functionally lead to an increase in soil hydraulic conductivity. The increased amount of macropores with size $r > 125$ µm in purple soil by honeysuckle planting and biochar application would lead to a more dominant role of the $r > 125$ µm pores in conducting water flow. Our findings suggest that the combination of honeysuckle planting and biochar may promote water infiltration and thus minimize the occurrence of surface runoff, which could help in water conservation and the reduction of soil erosion in farmland with purple soil.

5. Conclusions

A six-year field experiment was conducted to explore the interactive effects of honeysuckle planting and biochar addition on soil physical structure and hydraulic properties of farmland purple soil in hilly areas of the Sichuan basin, China. The results showed that honeysuckle planting alone could improve soil physical quality, and a greater improvement can be achieved by the implementation of both honeysuckle planting and biochar amendment. Soil aggregate stability can be enhanced by the combination of honeysuckle planting and biochar amendment. Biochar amendment significantly increased the saturated soil hydraulic conductivity directly or indirectly through increasing soil organic matter content. Both honeysuckle planting and biochar amendment can lead to a greater increase in saturated soil water content than saturated soil water conductivity. The findings of this study suggest that honeysuckle planting and biochar amendment can be considered as potential measures to improve soil quality and agricultural water management in sloping
farmland of purple soil and other similar soils that are prone to seasonal drought and soil erosion.

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**References**

1. Indoria, A.K.; Sharma, K.L.; Reddy, K.S. Hydraulic Properties of Soil under Warming Climate. In *Climate Change and Soil Interactions*, 1st ed.; Prasad, M.N.V., Pietrzykowski, M., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 450–507. [CrossRef]
2. Lu, J.; Zhang, Q.; Werner, A.D.; Li, Y.; Jiang, S.; Tan, Z. Root-Induced Changes of Soil Hydraulic Properties — A Review. *J. Hydrol.* 2020, 589, 125–203. [CrossRef]
3. Oades, J.M. The Role of Biology in the Formation, Stabilization and Degradation of Soil Structure. *Geoderma* 1993, 56, 377–400. [CrossRef]
4. Lynch, J. Root Architecture and Plant Productivity. *Plant. Physiol.* 1995, 109, 7–13. [CrossRef] [PubMed]
5. Gillet, F. Plant Competition. *Encycl. Ecol.* 2008, 5, 2783–2793. [CrossRef]
6. Hodge, A.; Robinson, D.; Griffiths, B.S.; Fitter, A.H. Why Plants Bother: Root Proliferation Results in Increased Nitrogen Capture from an Organic Patch When Two Grasses Compete. *Plant. Cell Environ.* 1999, 22, 811–820. [CrossRef]
7. Ennos, A.R. The Scaling of Root Anchorage. *J. Theor. Biol* 1993, 161, 61–75. [CrossRef]
8. Niklas, K.J.; Spatz, H.C. Allometric Theory and the Mechanical Stability of Large Trees: Proof and Conjecture. *Am. J. Bot* 2006, 93, 824–828. [CrossRef]
9. Vannoppen, W.; Vanmaercke, M.; De Baets, S.; Poesen, J. A Review of the Mechanical Effects of Plant Roots on Concentrated Flow Erosion Rates. *Earth-Sci. Rev.* 2015, 150, 666–678. [CrossRef]
10. Germann, P.F.; Lange, B.; Lüscher, P. Preferential Flow Dynamics and Plant Rooting Systems. In *Hydropedology Synergistic Integration of Soil Science and Hydrology*, 1st ed.; Lin, H., Ed.; Elsevier: Amsterdam, The Netherlands, 2012; pp. 121–141. [CrossRef]
11. Ni, J.; Leung, A.K.; Ng, C.W.W. Unsaturated Hydraulic Properties of Vegetated Soil under Single and Mixed Planting Conditions. *Geotechnique* 2019, 69, 554–559. [CrossRef]
12. Kammann, C.; Glaser, B.; Schmidt, H.P. Combining Biochar and Organic Amendments. In *Biochar in European Soils and Agriculture: Science and Practice*, Routledge: London, UK, 2016; pp. 136–164. [CrossRef]
13. Atkinson, C.J.; Fitzgerald, J.D.; Hipps, N.A. Potential Mechanisms for Achieving Agricultural Benefits from Biochar Application to Temperate Soils: A Review. *Plant. Soil* 2010, 337, 1–18. [CrossRef]
14. Wang, H.L.; Tang, X.Y.; Zhang, W.; Song, S.B.; McKenzie, B.M. Within-Year Changes in Hydraulic Properties of a Shallow Entisol in Farmland and Forestland. *Vadose Zone J.* 2015, 14, 1–15. [CrossRef]
15. Liu, C.; Wang, H.; Tang, X.; Guan, Z.; Reid, B.J.; Rajapaksha, A.U.; Ok, Y.S.; Sun, H. Biochar Increased Water Holding Capacity but Accelerated Organic Carbon Leaching from a Sloping Farmland Soil in China. *Environ. Sci. Pollut. Res.* 2016, 23, 995–1006. [CrossRef] [PubMed]
16. Zhang, J.; Amonette, J.E.; Flury, M. Effect of Biochar and Biochar Particle Size on Plant-Available Water of Sand, Silt Loam, and Clay Soil. *Soil Tillage Res.* **2021**, *212*, 104992. [CrossRef]

17. Zhao, P.; Wei, L.; Tang, X.; Hu, W.; Wang, H.; Liu, C. Does Biochar Amendment Influence Water Uptake Pattern of Winter Wheat (*Triticum aestivum*)? A Case Study in a Shallow Entisol. *Int. J. Agric. Biol.* **2020**, *24*, 935–944. [CrossRef]

18. Oladiipo, D.G.; Wei, K.; Hu, L.; Medaiyese, A.; Bah, H.; Gbadegesin, L.A.; Zhu, B. Short-term Assessment of Nitrous Oxide and Methane Emissions on a Crop Yield Basis in Response to Different Organic Amendment Types in Sichuan Basin. *Atmosphere* **2021**, *12*, 1104. [CrossRef]

19. Zhou, M.; Zhu, B.; Brüggemann, N.; Dannenmann, M.; Wang, Y.; Butterbach-Bahl, K. Sustaining crop productivity while reducing environmental nitrogen losses in the subtropical wheat-maize cropping systems: A comprehensive case study of nitrogen cycling and balance. *Agric. Ecosyst. Environ.* **2016**, *231*, 1–14. [CrossRef]

20. Zhu, B.; Wang, T.; Kuang, F.; Luo, Z.; Tang, J.; Xu, T. Measurements of Nitrate Leaching from a Hillslope Cropland in the Central Sichuan Basin, China. *Soil Sci. Soc. Am. J.* **2009**, *73*, 1419–1426. [CrossRef]

21. Thomas, G.W. Soil PH and Soil Acidity. In *Methods of Soil Analysis. Part 3. Chemical Methods*; Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Solanpour, P.N., Tabatabai, C., Johnston, T., Sumner, M.E., Eds.; Soil Science Society of America: Madison, WI, USA, 1996; pp. 475–490.

22. Zhong, R.-H.; Hu, J.-M.; Bao, Y.-H.; Wang, F.; He, X.-B. Soil Nutrients in Relation to Vertical Roots Distribution in the Riparian Zone of Three Gorges Reservoir, China. *J. Mt. Sci.* **2018**, *15*, 1498–1509. [CrossRef]

23. Nimmo, J.R.; Perkins, K.S. Aggregate Stability and Size Distribution. In *Methods of Soil Analysis. Part 4. Physical Methods*; Dane, J.H., Topp, G.C., Eds.; Soil Science Society of America: Madison, WI, USA, 2002; pp. 317–328.

24. Cui, J.; Tang, X.; Zhang, W.; Liu, C. The Effects of Timing of Inundation on Soil Physical Quality in the Water-Level Fluctuation Zone of the Three Gorges Reservoir Region, China. *Valose Zone J.* **2018**, *17*, 1–12. [CrossRef]

25. Giménez, D.; Perfect, E.; Rawls, W.J.; Pacheksky, Y. Fractal Models for Predicting Soil Hydraulic Properties: A Review. *Eng. Geol.* **1997**, *48*, 161–183. [CrossRef]

26. Tyler, S.W.; Wheatcraft, S.W. Fractal Scaling of Soil Particle-Size Distributions: Analysis and Limitations. *Soil Sci. Soc. Am. J.* **1992**, *56*, 362–369. [CrossRef]

27. McKenzie, B.M.; Dexter, A.R. Methods for Studying the Permeability of Individual Soil Aggregates. *J. Agric. Eng. Res.* **1996**, *65*, 23–28. [CrossRef]

28. Van Genuchten, M.T. A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils. *Soil Sci. Soc. Am. J.* **1980**, *44*, 892–898. [CrossRef]

29. Dexter, A.R.; Czyž, E.A.; Richard, G.; Reszkowska, A.A. User-friendly water retention function that takes account of the textural and structural pore spaces in soil. *Geoderma* **2008**, *143*, 243–253. [CrossRef]

30. Jirk, V.; Kode, R.; Nikodem, A.; Mühlhanselová, M.; Anna, Ž. Temporal Variability of Structure and Hydraulic Properties of Topsoil of Three Soil Types. *Geoderma*. **2013**, *205*, 43–58. [CrossRef]

31. Dexter, A.R. Soil physical quality: Part III. Unsaturated hydraulic conductivity and general conclusions about S-theory. *Geoderma* **2004**, *120*, 227–239. [CrossRef]

32. Vomocil, J.A.; Flocker, W.J. Degradation of Structure of Yolo Loam by Compaction1. *Soil Sci. Soc. Am. J.* **1965**, *29*, 7–12. [CrossRef]

33. Dexter, A.R. Soil Physical Quality: Part I. Theory, Effects of Soil Texture, Density, and Organic Matter, and Effects on Root Growth. *Geoderma* **2004**, *120*, 201–214. [CrossRef]

34. Dexter, A.R.; Czyz, E.A. Applications of S-Theory in the Study of Soil Physical Degradation and Its Consequences. *Land Degrad. Dev.* **2007**, *18*, 369–381. [CrossRef]

35. Andrade, R.S.; Stone, L.F. S Index as an Indicator of Physical Quality of Brazilian “Cerrado” Soils. *Rev. Bras. Eng. Agric. E Ambient.* **2009**, *13*, 382–388. [CrossRef]

36. Adamczyk, B.; Sietió, O.M.; Strakóva, P.; Prommer, J.; Wild, B.; Hagner, M.; Pihlatie, M.; Fritze, H.; Richter, A.; Heinonsalo, J. Plant Roots Increase Both Decomposition and Stable Organic Matter Formation in Boreal Forest Soil. *Nat. Commun.* **2019**, *10*, 1–9. [PubMed]

37. Bodner, G.; Leitner, D.; Kaup, H.-P. Coarse and Fine Root Plants Affect Pore Size Distributions Differently. *Plant. Soil* **2014**, *380*, 133–151. [CrossRef]

38. Hallett, P.D.; Fenn, D.G.; Engle, A.G.; Rilling, M.C.; Scrimgeour, C.M.; Young, I.M. Disentangling the Impact of AM Fungi versus Roots on Soil Structure and Water Transport. *Plant. Soil* **2009**, *314*, 183–196. [CrossRef]

39. Luo, W.; Li, J.; Song, L.; Cheng, P.; Garg, A.; Zhang, L. Effects of Vegetation on the Hydraulic Properties of Soil Covers: Four-Years Field Experiments in Southern China. *Rhizophere 2020*, *16*, 100272. [CrossRef]

40. Daynes, C.N.; Field, D.J.; Saleeba, J.A.; Cole, M.A.; McGee, P.A. Development and Stabilisation of Soil Structure via Interactions between Organic Matter, Arbuscular Mycorrhizal Fungi and Plant Roots. *Soil Biol. Biochem.* **2013**, *57*, 683–694. [CrossRef]

41. Zhao, P.; Tang, X.; Zhao, P.; Wang, C.; Tang, J. Tracing Water Flow from Sloping Farmland to Streams Using Oxygen-18 Isotope to Study a Small Agricultural Catchment in Southwest China. *Soil Tillage Res.* **2013**, *134*, 180–194. [CrossRef]

42. Lehmann, J.; Gaunt, J.; Rondon, M. Bio-Char Sequestration in Terrestrial Ecosystems — A Review. *Mitig. Adapt. Strateg. Glob. Change* **2006**, *11*, 403–427. [CrossRef]

43. Cha, J.S.; Park, S.H.; Jung, S.C.; Ryu, C.; Jeon, J.K.; Shin, M.C.; Park, Y.K. Production and Utilization of Biochar: A Review. *J. Ind. Eng. Chem.* **2016**, *40*, 1–15. [CrossRef]
44. Ntacyabukura, T.; Uwiringiyimana, E.; Zhou, M.; Zhang, B.; Zhu, B.; Harerimana, B.; Nambajimana, J.d.D.; Nsabimana, G.; Nsengumuremyi, P. Effect of Biochar and Straw Application on Nitrous Oxide and Methane Emissions from Eutric Regosols with Different pH in Sichuan Basin. *Atmosphere* 2021, 12, 729. [CrossRef]
45. Laird, D.A.; Fleming, P.; Davis, D.D.; Horton, R.; Wang, B.; Karlen, D.L. Impact of Biochar Amendments on the Quality of a Typical Midwestern Agricultural Soil. *Geoderma* 2010, 158, 443–449. [CrossRef]
46. Devereux, R.C.; Sturrock, C.J.; Mooney, S.J. The Effects of Biochar on Soil Physical Properties and Winter Wheat Growth. *Earth Environ. Sci. Trans. R. Soc. Edinb.* 2013, 103, 13–18. [CrossRef]
47. Blanco-Canqui, H. Biochar and Soil Physical Properties. *Soil Sci. Soc. Am. J.* 2017, 8, 687–711. [CrossRef]
48. Novak, J.M.; Busscher, W.J.; Watts, D.W.; Laird, D.A.; Ahmedna, M.A.; Niandou, M.A.S. Short-Term CO₂ Mineralization after Additions of Biochar and Switchgrass to a Typic Kandiudult. *Geoderma* 2010, 154, 281–288. [CrossRef]
49. Zhang, X.C.; Liu, X.H. Effect of Biochar on pH of Alkaline Soils in the Loess Plateau: Results from Incubation Experiments. *Int. J. Agric. Biol.* 2012, 14, 745–750.
50. Liang, B.; Lehmann, J.; Sohi, S.P.; Thies, J.E.; O'Neill, B.; Trujillo, L.; Gaunt, J.; Solomon, D.; Grossman, J.; Neves, E.G.; et al. Black Carbon Affects the Cycling of Non-Black Carbon in Soil. *Org. Geochem.* 2010, 41, 206–213. [CrossRef]
51. Bhogal, A.; Nicholson, F.A.; Rollett, A.; Taylor, M.; Litterick, A.; Whittingham, M.J.; Williams, J.R. Improvements in the Quality of Agricultural Soils Following Organic Material Additions Depend on Both the Quantity and Quality of the Materials Applied. *Front. Sustain. Food Syst.* 2018, 2, 1–13. [CrossRef]
52. Wang, D.; Fonte, S.J.; Parikh, S.J.; Six, J.; Scow, K.M. Biochar Additions Can Enhance Soil Structure and the Physical Stabilization of C in Aggregates. *Geoderma* 2017, 303, 110–117. [CrossRef]