Short Communication

Experimental Study of Influence of Biochar on Different Texture Soil Hydraulic Characteristic Parameters and Moisture Holding Properties

Tian Dan[1,2], Qu Zhong-Yi[1]*, Gou Mang-Mang[1,2], Li Bo[1], Lv Yi-Jia[1]

[1]College of Water Resources and Civil Engineering, Inner Mongolia Agricultural University, Hohhot, 010018 Mongolia
[2]Inner Mongolia Water Conservancy Science Research Institute, Hohhot, 010018 Mongolia

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Abstract

In order to reveal the performance mechanism of biochar for saving water by protecting fertilizer under different soil textures (based on the peanut shell biochar on sandy soil), we researched silt loam hydraulic characteristic parameters and the characteristic of water. Different biochar treatments (0, 0.05, 0.1, 0.15 g g^{-1}) of density, porosity, saturated hydraulic conductivity, saturated water capacity, and soil water retention curve were determined using the cutting ring, constant-head, and pressure membrane methods. The results show that the application of biochar can change sandy soil and silt loam structures. Sandy soil and silt loam bulk density decreased and sandy soil effective porosity increased with the increase of adding biochar, and all treatments of silt loam total porosity from big to small in turn 0.15, 0, 0.05, 0.1 g g^{-1}. Adding peanut shell biochar inhibited sandy soil water infiltration, and increased soil water-holding capacity and silt loam water-holding capacity in 0.15 g g^{-1} processing over control by 0.1, 0.05 g g^{-1} processing. In the same water potential cases for increasing biochar content, sandy soil water-holding performance enhancements, and silt loam hold water effect are not obvious. Therefore, the peanut shell biochar on the impact of different texture soil hydraulic parameters is inconsistent, and improving the soil structure and moisture performance effects of sandy soil is remarkable. The results of the study for biochar in sandy soil amelioration and utilization of water has a very important meaning and theoretical value.

Keywords: biochar, soil, total porosity, saturated hydraulic conductivity, moisture characteristic curve

Introduction

Biochar is the carbon-rich organic matter obtained by the slow pyrolysis of agricultural and forestry waste and other organic materials in condition anoxic or hypoxic [1]. Global biochar research began in the mid 1990s. In response to global warming, scientists recognized the importance of biochar for capturing carbon dioxide and as a carbon sequestration agent from Terra Preta's research of searching for more effective technology to reduce the atmospheric concentration of carbon dioxide and the carbon emission of fossil fuel, and research on biochar began [2-3]. Meanwhile, it was proven that biochar also had a significant effect on soil and crop yield improvement. Some research results have been obtained [4-6].

Gundale et al. [7] and Yan et al. [8] found that biochar could reduce soil bulk density and increase specific surface area and carbon pool reserves of soil; the studies of Keech et al. [9] and Liang et al. [10] showed that biochar could

*e-mail: quzhongyi68@sohu.com
913234212@qq.com

improve soil cation exchange capacity and increase the soil adsorption capacity of fertilizer; Novak et al. [11] found that biochar was generally alkaline, which could improve the acidic soil and increase the pH of soil. The addition a dosage should not be too large; Yuan et al. [12] applied biochar in red and yellow brown soil, and the pH value and base saturation for two kinds of soil were improved to a different extent. The studies of Tryon [13] and Dugan et al. [14] showed that the application of biochar in sand soil could improve water-holding capacity of soil. However, Tryon found the soil moisture of clay soil decreased with the addition of biochar. This was probably caused by the hydrophobicity of fresh biochar.

Hall et al. [15] found that biochar could improve the cation exchange capacity (CEC) of soil, and high CEC was beneficial for nutrient preservation of soil. Meanwhile, a certain amount of mineral nutrients contained in biochar could increase the Ca, Mn, K, P, and N element contents of soil, especially for sandy soil [16-17]. Hockaday [18] found that the pores and surfaces of biochar could store large amounts of water, nutrients, and air, which provided the conditions for the aggregation and survival of microbes. Kolb et al. [19] found that the application of biochar affected the microbial biomass and microbes activities of soil, which was good for the decomposition and utilization of nutrients. Thorough quantified studies of the biochar's water-holding mechanism and the mechanism for the effect of soil aggregate stability on water-holding characteristics in large clusters are still very scarce despite the fact that biochar have been proven to improve water-holding capacity of soil in a large number of studies, reduce leaching loss of nutrients in the soil, promote nutrient cycling, and improve crop yield. Chinese research on environmental behavior and effect of biochar are still in the initial stage. The present studies only involve biochar's effect on the physical chemistry properties of soil-soil water-holding characteristics, plant growth [20-22], an research on the adsorption mechanism of heavy metal and ammonia [23]. Most studies and lacked quantitative research, particularly in biochar's effects on improvement of soil with different textures, coupling efficient utilization of water and fertilizer, soil hydraulic parameters, and solute transport law. This research, on the basis of previous studies, regarded peanut shell biochar as the testing material and focused on biochar's effect on bulk density, porosity, hydraulic conductivity, saturated water content, and water-holding characteristics of sand soil and silt loam soil to provide the basis for further research on biochar's mechanism and application to different textured soils.

Material and Method

Test Material

Soil

The soil was 0-20 cm silt loam taken from the test site in Wulateqianqi of Bayannaoer City and sand soli from the test site in Helin county. The soil samples were air-dried and ground over 2 mm-sieve for reserve. Soil particle composition was analyzed and calculated utilizing a laser particle size analyzer (Bbckm-conl-trels-230) and Fraunhofer theoretical model. The basic properties of tested soils are shown in Table 1.

Table 1. Basic physical properties.

Soil texture	Bulk density (g cm^{-3})	Total porosity (%)	Sand (%)	Powder particle (%)	Clay (%)
Sandy soil (I)	1.54	36.45	87.78	11.16	1.06
Silt loam (II)	1.39	48.03	24.31	62.09	13.6

Biochar

The testing biochar was peanut shell biochar *procured* from Shenyang biochar fertilizer plant. It was ground over a 2 mm-sieve for reserve. Test analysis found that the contents of carbon, nitrogen, potassium, calcium, and iron in peanut shell biochar were 663.151 g kg^{-1}, 13.851 g kg^{-1}, 4.686 g kg^{-1}, 25.865 g kg^{-1}, and 11.111 g kg^{-1}, respectively pH value of the biochar was 7.937.

Experiment Design and Measurement Method

The bulk density and porosity of soil were measured through cutting ring method. The dried sand and silt loam soil were mixed with peanut shell biochar in a ratio of 0, 0.05, 0.1, 0.15 g·g^{-1} before the test, and each treatment was repeated three times. 100 cm^3 standard cutting ring was utilized for the soil loading. The bulk density of sand and silt loam soil in the soil-loading process was controlled at 1.54 g cm^{-3} and 1.39 g cm^{-3}. The strike number and pressure of other treatment and filling processes were consistent with the control group. The weight of each cutting ring was measured. The dry bulk density for each soil sample was calculated by the formula: dry bulk density = (loaded weight of soil cutting ring-ring knife weight)/ring knife volume.

Then each soil sample was soaked in a container until saturation. The weight of the saturated soil was weighed and recorded for calculating the saturated water content of soil samples, and each processed soil was placed in a flat-bottom plate covered with dry sand. The weight of soil sample was weighed and recorded after 2 h (for calculating the soil capillary moisture), and the soil samples were dried to a constant weight in a constant temperature of 105ºC. The weight of each dry soil sample was measured, and soil total porosity was measured by the following formulas according to the tested data:

$$\text{Saturated water content (\%)} = (\text{saturated weight} - \text{dry soil weight}) / \text{dry soil weight} \times 100 \quad (1)$$

Capillary moisture capacity (%) = (weight after 2h on sand - dry soil weight) /dry soil weight × 100 (2)

Capillary porosity (%) = capillary moisture × soil bulk density (3)

Non-capillary porosity (%) = (saturated water content - capillary moisture capacity) × soil bulk density (4)

Total porosity (%) = capillary porosity + non-capillary porosity (5)

Constant water head method was utilized for the determination of saturated hydraulic conductivity of soil samples, and the experimental design was consistent with the experimental design of measuring soil bulk density and porosity. The test instrument for saturated hydraulic conductivity was restructured from the South 55 infiltration rate meter, and the instrument was made by water resource R & D office of Xi'an University (Fig. 1). Tested soil column was a transparent plexiglass tube with 5 cm diameter and 12 cm height; water supply system was Markov bottle with cross-section area of 15 cm^2; water head of sand soil was controlled at 13-14 cm; water head of silt loam was controlled at 167-169 cm. The soil was considered to be saturated when the water out of the outlet maintained a certain amount for a consistent time after being placed in a certain water head for some time. Then the determination began: the water flow of each treated sand sample was measured once every 30min; the water flow of each treated silt loam was measured once every 60min. The saturated hydraulic conductivity for each soil was calculated by the formula:

$$K = VL / hAt \qquad (6)$$

...where:
- K – saturated hydraulic conductivity
- V – water volume under a certain time
- L – length of soil sample
- h – the water head difference
- A – the cross-section area of soil sample
- t – the seepage time

The pressure membrane method was utilized for measuring the water-holding characteristics of treated soil. The soil was loaded in accordance with the measured bulk density of each treated soil, and the cutting ring was 100 cm^3. Loaded soil samples were immersed in a water container until saturation. The saturated weights of soil samples were recorded. Then the soil samples were placed into a membrane pressure instrument at pressures of 2, 4, 6, 8, 10, 12, 50, 70, 200, 400, 800, and 1000 Kpa. Sandy soil and the treatment group was maintained for 24 h, Silt loam and each treatment group was maintained for 48 h, and the soil samples were removed and weighed. The measured moisture stress of each soil sample was utilized for drawing a soil moisture characteristic curve.

Results and Discussion

The Effect of Adding Peanut Shell Biochar on Bulk Density and Porosity of Sand and Silt Loam Soil

The variation laws of density and porosity under four different treatments (0,0.05,0.1 and 0.15 g g^{-1}) of peanut shell biochar in sand and silt loam are shown in Fig. 1. The bulk density of silt loam and sand soil, seen from Fig. 1, increase with the decrease of biochar content. However, the porosity variation laws for two soil samples are inconsistent: sand porosity increases with increase in biochar content while the porosity of silt loam soil is reduced with 0.05,0.1 g g^{-1} treatment. The porosity of silt loam soil with the treatment of 0.15 g g^{-1} slightly increases compared with the control group. The increase of sand porosity is because porous structure and larger quantities pore in different shapes of peanut shell biochar can fill the soil macropores and split them into many micropores. Meanwhile, the porous structure of biochar is one of the reasons for the increase of sand porosity. Loam soil porosity ranges from 45% to 52%, while the porosity of sand soil with the additive biochar in the study ranges from 41.29%-48.71%, which indicates that sand porosity gets close to loam soil porosity with the increase in the additive amount of biochar in sand soil. It is of great significance for the structure improvement of sand soil. The increase of silt loam soil porosity needs a large amount of additional biochar, which is not suitable for field application.

The Effect of Peanut Shell Biochar on the Saturated Hydraulic Conductivity of Sand and Silt Loam Soil

The saturated conductivity for treated sand and silt loam soil was measured utilizing the constant head method. Tested saturated hydraulic conductivity and saturated mass moisture content of sand and silt loam in soil under different treatments of peanut shell biochar are shown in Table 2.

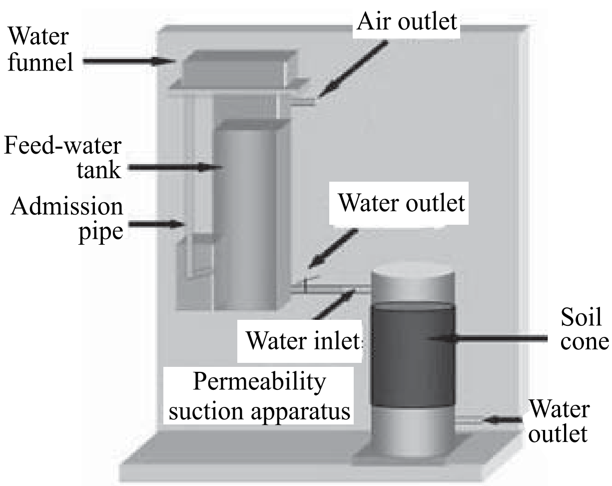

Fig. 1. Soil saturated hydraulic conductivity test apparatus.

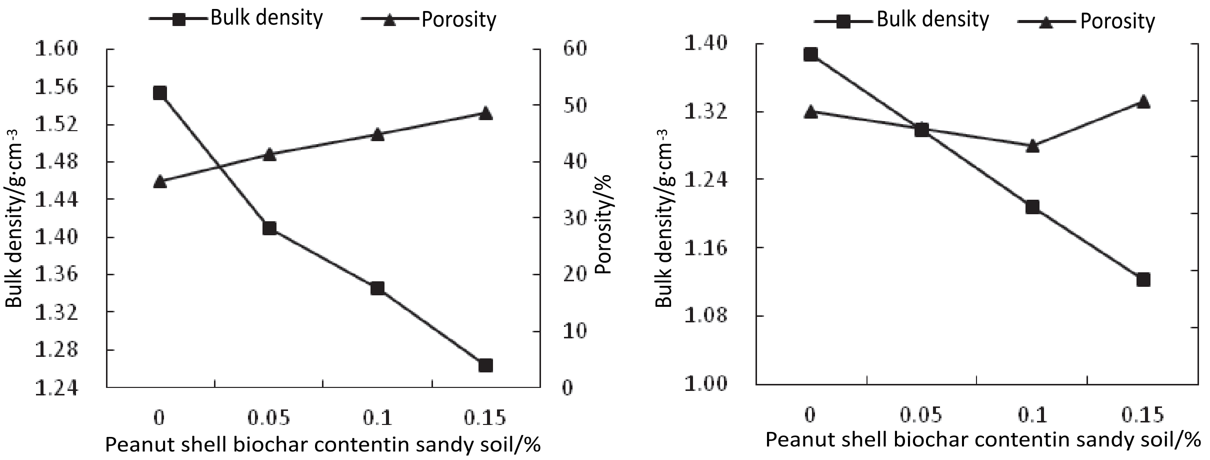

Fig. 2. Sand and silt loam under the different ratio of peanut shell biochar bulk density, porosity change rule.

The saturated hydraulic conductivity of sand soil in Table 2 shows a decreasing trend with the content increase of peanut shell biochar while saturated hydraulic conductivity of silt loam soil shows an increasing trend with the content increase of peanut shell biochar. The saturated hydraulic conductivity of each treated sand soil, from significant analysis is significantly different with the control group; however, there is no significant difference among the treated soil samples; the saturated hydraulic conductivity of each treated silt loam soil is significantly different with the control group, and there is significant difference among the treated soil samples. The saturated hydraulic conductivity for 0.05, 0.1, 0.15 g g^{-1} treated sand decreased by 82.16%, 90.74%, 95.30%, respectively, compared with the control group; saturated hydraulic conductivity for 0.05, 0.1, 0.15 g g^{-1} treated silt loam soil increased by 30.98%, 70.62%, 76.44%, respectively, compared to the control group. The results showed that additive peanut shell biochar could effectively suppress the water loss of sand soil, and the water conductivity for silt loam soil also increased.

The effects of peanut shell biochar on the saturation moisture of sand and silt loam soil were different: sand-saturated moisture showed an increasing trend with the increase of biochar content while the saturated moisture content of silt loam showed the maximum in 0.15 g g^{-1} treatment, and was slightly smaller than the control group at 0.05,0.1 g g^{-1}. The saturation moisture of sand and silt loam soil, from significant analysis, had significant differences with the control group. Saturated moisture content for and 0.05, 0.1, 0.15 g g^{-1} treated sand increased by 28.38%, 56.13%, 89.14%, respectively, compared with the control group; saturation moisture for 0.05, 0.1 g g^{-1} treated silt loam soil decreased by 0.49%, 2.76%, respectively, compared with the control group. Saturation moisture for 0.15 g g^{-1} treated silt loam soil increased by 28.05% compared with the control group.

The results showed that additive peanut shell biochar could increase the moisture content of sand soil, and the water-holding capacity of sand became stronger with the content increase of biochar. Silt loam soil, however, had a stronger water-holding capacity only with a large amount

Table 2. Sand and silt loam under different ratio of peanut shell biochar hydraulic conductivity and saturated water content value.

Treatments	Saturated hydraulic conductivity (cm/d)	Significant analysis		Saturated water mass fraction (%)	Significant analysis	
		0.05	0.01		0.05	0.01
P I (0)	29.418	A	a	23.74	A	a
P I (0.05)	5.247	B	b	30.49	B	b
P I (0.1)	2.725	B	b	37.08	C	c
P I (0.15)	1.382	B	b	44.92	D	d
P II (0)	0.176	A	a	34.48	C	c
P II (0.05)	0.255	B	b	34.31	B	b
P II (0.1)	0.599	C	c	33.53	A	a
P II (0.15)	0.747	D	d	44.15	D	d

I sandy soil, II silt loam; P peanut shell biochar; 0, 0.05, 0.1 and 0.15 g g^{-1} four formula of biochar. The data use SPSS statistical software to analyze different treatments at P = 0.05 and P = 0.01 levels of significant differences.

Table 3. Sand and silt loam under different ratios of peanut shell biochar Van Genuchten par.

Treatments	Van Genuchten model parameters		
	α	*n*	R^2
P I (0)	0.0203	1.2436	0.979
P I (0.05)	0.0237	1.0946	0.992
P I (0.10)	0.0196	1.0824	0.990
P I 3 (0.15)	0.0167	1.0805	0.990
P II (0)	0.0217	1.1468	0.999
P II (0.05)	0.0223	1.0936	0.994
P II (0.10)	0.0254	1.0840	0.996
P II (0.15)	0.0712	1.0454	0.989

of additive peanut shell biochar. The moisture content of the soil would be lowered when the additive amount was small.

Some studies have confirmed that the effective pore size of soil is larger than 0.3 mm, which water can freely pass through. Water can easily pass through pores with diameter of 0.3-0.03 mm by gravity. Pores with effective pore size smaller than 0.03 mm would not allow water to pass freely. And soil porosity was the main factor for the saturated hydraulic conductivity of disturbed soil [24]. The study has confirmed that biochar additive can increase the total porosity degree of sand soil. And the saturated hydraulic conductivity rate reduced. This might be because additive biochar mainly increased small pores in sand soil, and water was not easy to flow through this part of the pore under gravity. The reason for the change in saturated hydraulic conductivity of silt loam soil was that the addition of biochar changed the original soil pore structure: the soil macropores increased while the medium and small pores decreased. The increased soil macropores became larger with the increasing content of biochar, and more water would flow out of the large pores under gravity, which made the soil saturated hydraulic conductivity of silt loam increase with the increasing content of biochar. The laws for the large, medium and small porosity variations of sand and silt loam soil after adding biochar need further study.

The Effect of Peanut Shell Biochar on Moisture Characteristic Curve Parameters of Sand and Silt Loam Soil

Moisture – water potential data or moisture – water conductivity data can be observed by RETC software [25] and utilize non-linear least square optimization to estimate the unknown model parameters. Van Genuchten model and the relation m = 1-1/n was utilized for water characteristic curve simulation. The moisture characteristic curve equation of soil includes parameters: θs (saturated soil moisture), θr (residual soil moisture), *a* (intake suction parameter), *m* (curve shape parameter), and *n* (curve shape parameter). RETC software can fit one, several or even all of the parameters at the same time. Firstly the predicted values for each parameter could be obtained by the neural network prediction function of RETC software based on the soil texture data and density data. These predicted values were regarded as initial input parameters of RETC software when fitting parameters, and these parameters were combined with the measured data through RETC software for recalibration.

a, n and the value of correlation coefficient R^2 obtained from fitting results are shown in Table 3, and the moisture characteristic curve model of peanut shell biochar of treated sand and silt loam soil is shown in Fig. 2. The intake suction parameters *a* and shape variation coefficient *n* of treated sand and silt loam soil are shown in Fig. 3.

The correlation coefficients for model fitting and measuring values of peanut shell biochar treated sand and silt loam, seen from the data in Table 3, are all larger than 0.97, which indicates that Van-Genuchten model fitting results of soil moisture characteristic curves utilizing RETC software are credible. Moisture content of sand, as can be seen from Fig. 1, increased with the biochar content under the same soil suction; the moisture content of P I (0.05), P I (0.1), P I (0.15) soil increased

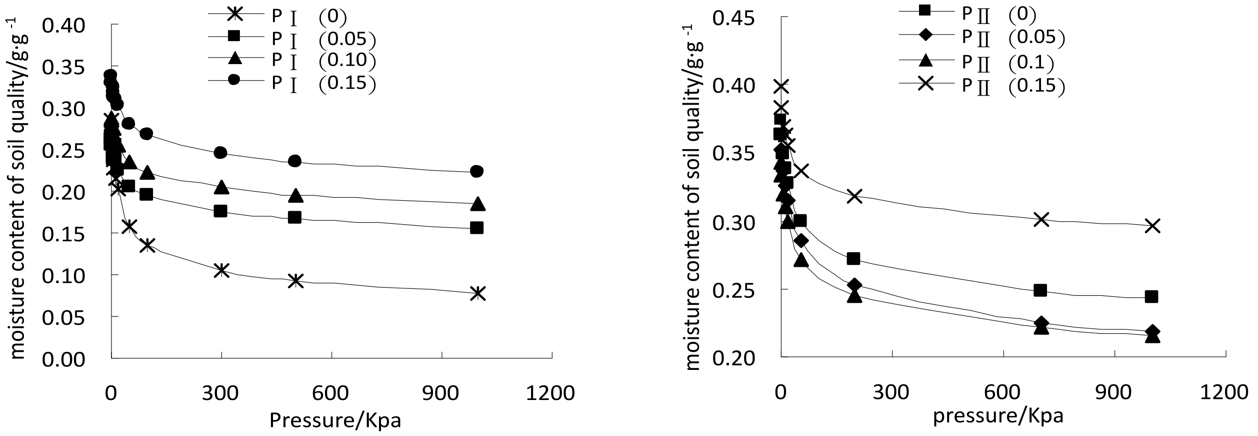

Fig. 3. Peanut shell biochar processing sand and silt loam moisture characteristic curve fitting.

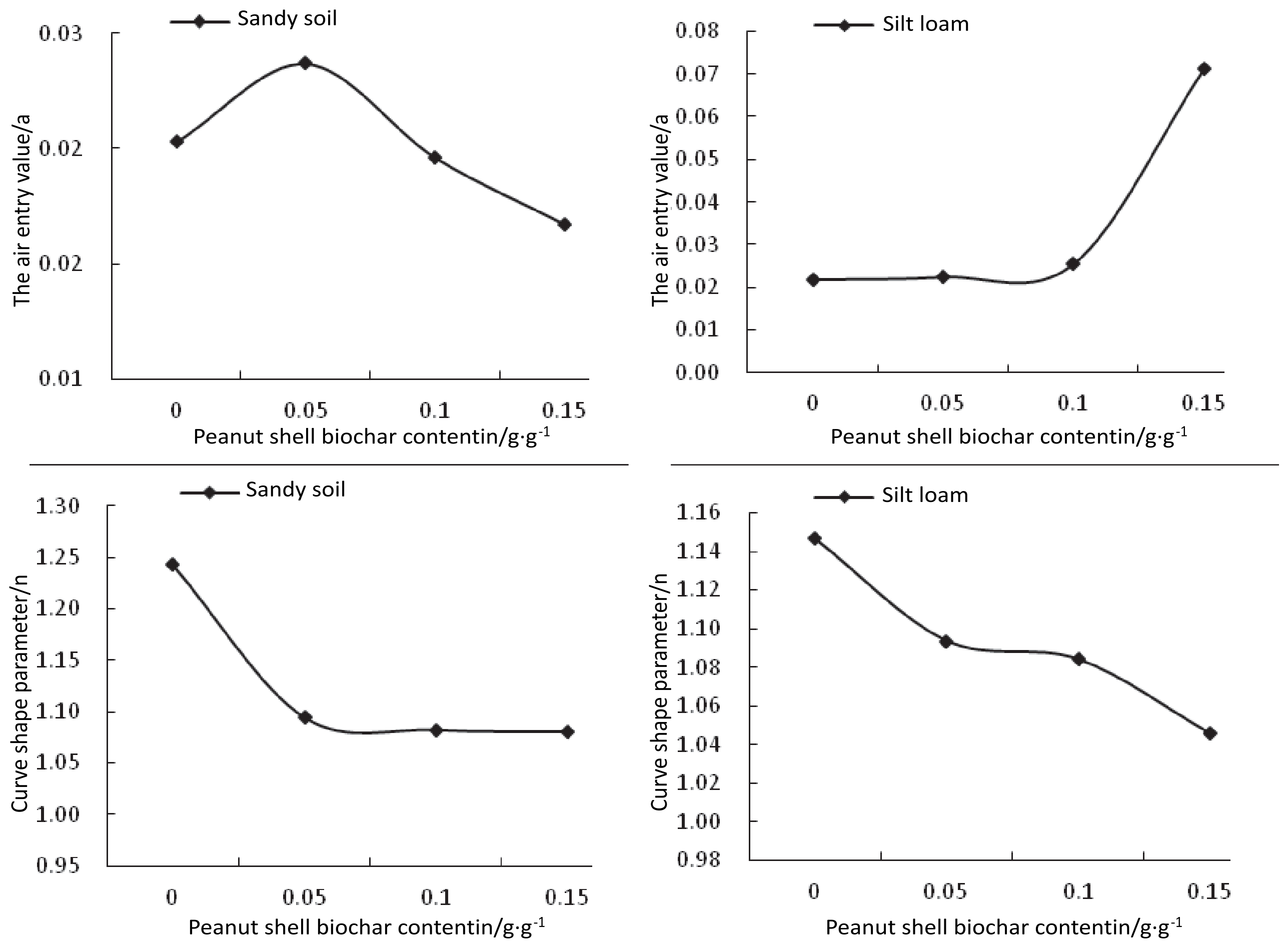

Fig. 4. Peanut shell biochar processing sand and silt loam the air entry value and curve shape parameter of the change rule.

compared with the moisture content of pure sand when the suction changed at 2-1000KPa, and the variation range was 0.92%-16.89%; relatively large pressure led to more obvious differences in moisture content between biochar-treated sand and pure sand. The effect of additive biochar on water-holding capacity of silt loam soil was irregular: the soil moisture of P II (0.15) was larger than the control group, while P II (0.05) and P II (0.1) were smaller than the control group under the same soil suction. The main factor for the changing moisture content of sand in this experiment might be that the sand porosity, as biochar content increased, became larger and more intensively affected the water holding capacity of soil. Wherein, the increase extent of micropores was larger than the increase extent of macropores. The water in large pores firstly flowed out under the same water suction of soil, while the water in small pores was less affected by suction force. Less water flowed out of small pores under the same suction, and this indicated that the additive biochar could increase the water-holding capacity of sand soil. The water holding capacity variation, for the silt loam, was consistent with the variation of porosity. The porosity and water-holding capacity at 0.15 g g^{-1} increased compared with other treatments. The porosity and water-holding capacity of 0.05, 0.1 g g^{-1} treatment were smaller than the control group, which indicated that porosity was the main factor for the water-holding capacity of silt loam soil. A small amount of additive biochar had significant influence on the soil macropores: water easily flowed out of soil under a certain pressure, and the water-holding capacity of soil was reduced. A large amount of additive biochar had greater impact on the small pores: water of this part could not easily flow out of the pores, and the water-holding capacity of soil increased.

Value a of the 0.05 g g^{-1} treatment sand increased when compared with the control group, 0.1 and 0.15 g g^{-1} treatment sand decreased when compared with the control; value a of silt loam soil increased with the biochar content, and the value of 0.15 g g^{-1} treatment was significantly larger than other treatments, while value a of 0.05 and 0.1 g g^{-1} treatment was only slightly larger than the control group. Value n of the treated sand and silt loam soil increased with the content of peanut shell biochar (Fig. 4).

Discussion

The addition of peanut shell biochar can change the physical properties of sand and silt loam soil, and the improvement effects were different. The soil saturated water content and soil moisture content increased while soil hydraulic conductivity decreased with peanut shell biochar in sand soil and soil hydraulic conductivity increased, while soil-saturated water content and soil moisture content decreased with peanut shell biochar in silt loam soil. This has to do with Gao hai ying etc. [22] research results, for sandy soil is added biochar can reduce soil permeability, inhibiting water infiltration and soil moisture increase performance, for the viscous silt loam texture, added biochar can increase soil permeability and promote soil water infiltration. Tryon [26] researched biochar on the influence of different texture in the soil moisture, research shows that in the sandy soil with biochar can increase 18% of the available soil water; however, the phenomenon is not observed in fertile soil, and effective in clayey soil water content decreases with the addition of biochar. Added biochar can reduce soil bulk density. Similar to other related research results, Laird etc. research shows that applying biochar significantly reduced soil bulk density compared with blank soil. Eastman in silty soil application of 25 g/kg of biochar, soil bulk density decreased to 1.33 from 1.52 g/cm^3 g/cm^3. Verheijen [27] studies suggest that biochar may jam the soil pore, making fine particles of water permeability reduced, and the visible biochar effect on porosity and this research is consistent.

Conclusion

Applying biochar to sandy soil, the soil bulk density and water conductivity of sandy soil decreased while porosity, saturated water content, and water content under the same pressure increased with the increasing addition of peanut shell biochar in sandy soil. It indicated that the addition of peanut shell biochar could increase the moisture content and water-holding capacity of sand soil. Applying biochar to silt loam soil, bulk density of silt loam soil decreased with the increasing addition of peanut shell biochar, while its porosity only increased under 0.15 g g^{-1} treatment compared with the control group, and porosity of another two treatments, compared with the control group, was reduced. The variation laws of moisture content and water-holding rate were the same with porosity, which indicated that only peanut shell biochar with a large amount could improve the water holding capacity of silt loam soil and the improvement was not significant. This study showed that applying a suitable amount of biochar can significantly improve the water holding capacity for sandy soil, and inconsistencies showed in the studies of loam soils.

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