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Research Article

Effect of Corn Stalk Biochar on the Evolution of Water Evaporation and Cracking of Soil

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The evolution of water evaporation and cracking of soil affected by corn stalk biochar is experimentally investigated. Water evaporates from the soil surface, causing shrinkage in soil body and forming cracks, which significantly lead to crop nutrient loss, groundwater pollution, and land salinization. Biochar is a recyclable natural material widely used in improving the water retention and suppression of cracking of soils. Free desiccation tests were conducted with adding the biochar contents of 0%, 4%, and 8%. The variation of water evaporation amount and the development of cracking were recorded and disposed. The results show that the evaporation process can be changed due to the addition of biochar contents. The evaporation rate can be divided into three phases of a constant rapid evaporation phase, a fluctuated evaporation phase, and a residual evaporation phase. A sudden increase at around 30% of moisture content in evaporation rate indicated that the crack began to develop and extend greatly, which increased the evaporation surface area. The residual moisture contents of soils with biochar contents of 4% and 8% increased by 105.56% and 88.38% than those of soil without biochar, respectively. The crack ratio reduced by 32.39% and 15.31% with the addition of biochar contents of 4% and 8%, respectively. A three-level crack was observed during evaporation process, where a second and third crack developed less with the addition of biochars. The corn stalk biochar improves the integrity of soil bodies and increases the connection of soil particles for more water storing between the biochar particles and soil particles. It can be concluded that corn stalk biochars are able to delay the evaporation and cracking developing in cohesive soils, which may be beneficial for crops in dry area.

1. Introduction

Water retention capacity and cracking properties of soil are significant in dry climatic regions. Desiccation caused by water evaporation can induce severe cracking in unprotected landfill cover system [1–3]. During desiccation process, a lot of water evaporates through the surface of soils, causing the soil body to shrink, gradually dry out, and form cracks. Crack network greatly changes soil structure [4, 5], influences the hydraulic behaviors [6, 7], even forms permeability paths, and causes various geotechnical and geological environment problems, such as soil settlement of embankment, stress relief, landslide and debris flow, and avoidance of accelerated transport of pollutants in clay barrier layers of landfill [8–12].

It is a natural phenomenon that the surface of cohesive soil cracks when it shrinks after desiccation. Mechanical parameters change greatly when soils are in saturated state, wet state, and dry state [13]. The presence of cracks alters the properties of soil surface and effectively changes water infiltration and evaporation patterns. Cohesive soils are widely used in the construction of buffer layer, lining, and overburden layers with the property of low water conductivity, so it can be used as aquitard. Dry cracks forming in these structures contribute the controlling routes for hydraulic properties. In other words, increasing cracks dramatically increase water conductivity, resulting in invalidation in barrier system [14–16]. The hydraulic conductivity of liner materials with cracks can increase by 500 times that that of the original soil. In addition, these

cracks caused by shrinkage also form weak zones in soil body, reducing the overall mechanical strength and bearing capacity and increasing compressibility [17–19]. Dry cracks developed on the ground surface can lead to crop nutrient loss, groundwater pollution, and surface water pollution because these cracks control the rate and speed at which water, solutes, pollutions, and microorganisms migrate in soil system [20, 21].

Biochar is a solid material produced from different waste biomass residues under different limited oxygen conditions. It can be used to improve water retention capacity and suppression of cracking of soils due to its high specific surface area and porous structure [22–25]. Biochars can change the hydraulic properties of soil body and retain a large amount of water and nutrients inside the soil system. Other materials such as fiber, silica powder, and microorganism have also been added into soils to suppress cracks [26–30]. Kalkan [31] proposed that silica fume can decrease the development of desiccation cracks of the soil samples. Gunal et al. [32] investigated the effects of three biochar types, which were produced from rice husk, bean harvest residue, and corn cobs, on available water contents of sandy loam and loamy soils. All these biochar types increased the available water contents in both soil types; the increasing value was more significant in the loamy soil samples. Bordoloi et al. [33] conducted a series of tests on soils mixed with biochar contents of 0%, 2%, 5%, and 10% by weight to study the variation of water content and crack intensity factor. With the increase of biochar contents, the water retention capacity increased and cracking was controlled, and 10% of biochar content was regarded as the best value of agricultural purpose. The solution leaching volume in soils has been effectively decreased with the application of biochar, and there is a negative correlation between biochar contents and leaching volumes [34]. Albrecht and Benson [35] investigated that the geometrical structure of cracking largely controlled the hydraulic conductivity, and the volumetric shrinkage strains were affected by soil properties.

In arid and semiarid regions, the cracking of soil body caused by water evaporation is very important to the mechanical properties of soil. Soil cracking, salinization, and degradation are caused by the interaction of soil internal and external environment. A defining feature of drought is the desiccation of soils exposed to large gradients of temperature and humidity conditions. Additions can be added to reduce the cracking phenomenon in most situations. In this study, corn stalk biochar was added in soil samples collected from the Yellow River Basin to study the influence of biochar contents on soil cracking property and water retention capacity. Different biochar contents of 0%, 4%, and 8% by weight were designed to find the way to reduce water evaporation and development of dry cracks in soil bodies. The research provides the experimental tests and analysis in alleviating the variation of cracking and evaporation properties in cohesive soil with biochar additives.

2. Materials and Method

2.1. Test Materials. Soil samples investigated in this study were collected from the Yellow River Basin located in Jiaozuo, Henan, China, where drought events have occurred. The soil samples belong to the yellow brown cohesive soil formed under the historical deposition of the Yellow River. The samples were collected at a depth of 0.5-1.0 m, and the topsoil was removed to avoid the effect of roots or small rocks. The basic index properties of the soil were tested and summarized in Table 1.

Biochar can improve water retention capacity, hydraulic conductivity, and infiltration rate of soils [36, 37]. More water retains in pores between biochar particles and in the pores formed by soil particles and biochar particles. Biochar prepared from corn stalk is widely used as addition of phosphorous in agriculture and increases water retention capacity of soils [38–40]. The corn stalk biochar has been widely industrial produced as a commonly used biochar type [41]. Due to a large number of corn planted in the Yellow River Basin in China, large amounts of corn straws are produced every year. Corn stalk biochar can effectively consume a large amount of corn straws, and it can also improve the structure and mechanical properties of soils. The corn stalks are collected when they are dried and cut into small pieces and burnt in the absence of air at a certain temperature of 400°C, 500°C, and 600°C or higher. Finally, the corn stalks are crushed and turned into biochars in type of C400, C500, and C600 [42]. The corn stalk biochar used in this study is C500 which is burnt at the temperature of 500°C with a maintained time of 4 h [43].

2.2. Method. The soil samples were put in the oven with a temperature of 110°C drying for 24 h. Then, the soil samples were crushed into unconsolidated particles and filtered through a sieve with an aperture of 2 mm. Those soil particles less than 2 mm were obtained and prepared as 6 groups for testing, three of which were set as parallel tests. In order to study the influence of different corn stalk biochar contents on the water evaporation and cracking properties of soil samples, the soil samples (200 g for each group) were mixed with different biochar contents of 0 (0 g), 4% (8 g), and 8% (16 g) by weight for both testing groups and parallel groups. The soil particles and biochar were mixed evenly to decrease the effect of biochar distribution and placed in the glass containers. Then, water was added and stirred to make the soil particles and the corn stalk biochars fully integrate into a saturated slurry. The moisture content was set as 110% for each group samples to ensure the uniformity of the initial state. The mixed slurry was placed on an electronic scale, and the evaporation process was carried out at a room temperature of 25°C for naturally drying. The weight change of the mixed slurry was recorded using the electronic scale every 5 hours. Then, moisture content and evaporation rate can be calculated by Equations (1) and (2), respectively.

$$w = \frac{m - m_s}{m_s} \times 100\%, \tag{1}$$

$$E_r = \frac{\Delta m}{A \cdot T}, \tag{2}$$

where w is the moisture content of the slurry mass (%). m is the total quality of the saturated slurry mass (g). m_s is the

Table 1: Basic index properties of the tested samples.

Density (g/cm^3)	Water content (%)	Liquid limit	Plastic limit	Plasticity index	Particle size distribution (%)		
					Clay	Silt	Sand
2.65	35	34.8	17.1	17.7	56	32	12

quality of the dry soil particles (g). E_r is the evaporation rate ($g/(cm^2 \cdot h)$). Δm is the decrease value of moisture content as the amount of solid is constant (g). A is the surface area of the soil sample, the same as the area of the container (cm^2). T is the interval time of two records (h).

To obtain the cracking properties, the cracking process was photographed with a digital camera placed right above the samples at the same time the weight was recorded. The image processing was conducted with a software called ImageJ. The original crack images were converted to binary images with edge detection and threshold segmentation. The crack images were firstly cut to remove the boundary part in order to exclude the boundary influence of the processing. Then, gray image was transformed as color information is unfavorable to the calculation of cracking properties. The crack was clearer after the color image converting to the gray image. By selecting a proper threshold, the image was binarized, and only black and white were left in the crack image. The last step was image denoising. These noises were removed, and the edge of cracks were clearer after median filter [44, 45].

3. Results and Discussion

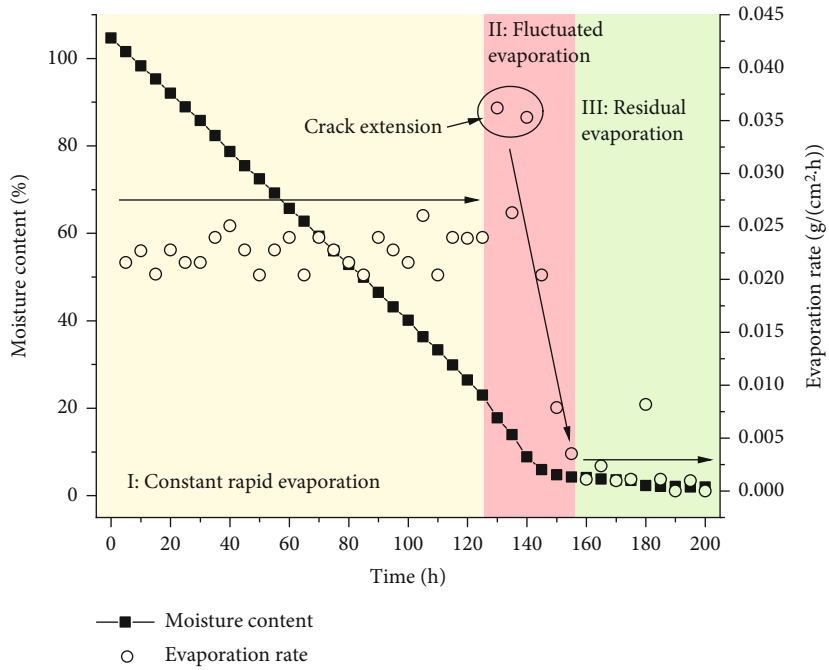
3.1. The Effects of Corn Stalk Biochar on Evaporation Property. Water evaporation tests were conducted with original soil sample and soils mixed with 4% and 8% of corn stalk biochars. The evolution of evaporation properties soil samples was drawn in Figure 1, containing the variation of moisture content and evaporation rate. The interval of data collection was 5 hours, and the total collection time was 200 hours, until the final moisture content basically did not change.

During the continuous water evaporation process, the variation of moisture content with different biochar contents showed a similar three-phase process. For the first phase, the relationship of moisture content and the collection time showed a linear variation; that is, the evaporation rate was almost the same, which is called a constant rapid evaporation phase. Mainly free water on the surface of the soils is lost during this stage. The biochar contents have little effect on the evaporation process in this phase. In the second phase (fluctuated evaporation phase), the curve of moisture content did not show a linear change, but with a significant concave curve. Cracks appeared on the surface of the soil on a large scale, and the contact area between the biochar particles, soil particles, and air increased and became the main route for water migration. The moisture content at the beginning of this phase is approximately equal to the nature water content of this soil sample. During the third phase (residual evaporation phase), the moisture content did not have significant change, indicating the residual moisture content of each soil sample. Only strongly bound water remained in the micropores of the biochars and soils. The residue average moisture contents of soil samples without biochar and soil samples with 4% and 8% of corn stalk biochar contents were 1.98%, 4.07%, and 3.73%, respectively, which showed that the addition of biochar can significantly increase the water retention capacity of soils.

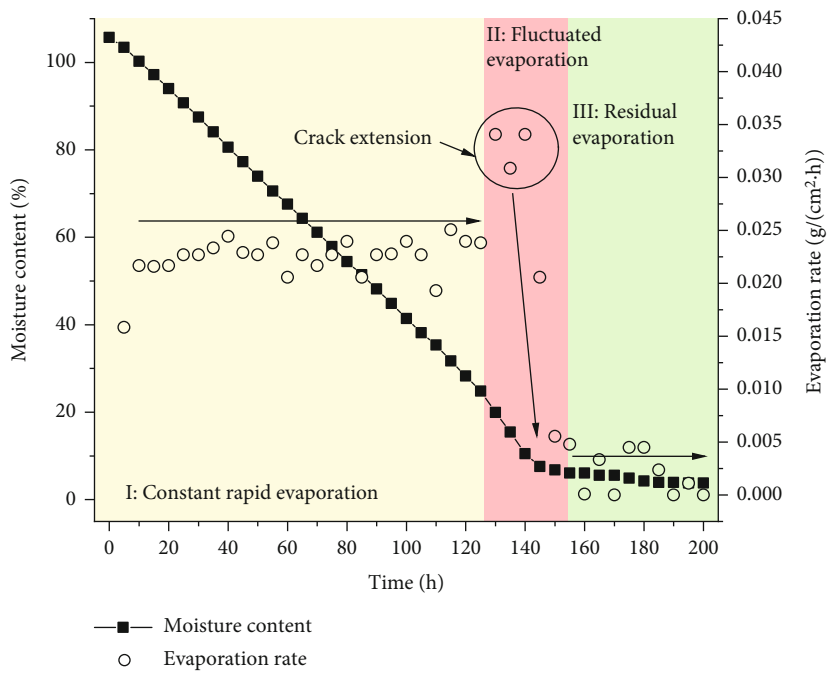
The evaporation process also stated three phases of a constant rapid evaporation phase, a fluctuated evaporation phase, and a residual evaporation phase, which is consistent with phases of moisture content. In the early phase, the average evaporation rates of soil samples with different biochar contents are approximately equal. The first phase lasts for about 125 h. The fluctuated evaporation phase shortened with the increase of the biochar contents. The value of the maximum evaporation rate of 0.035 $g/(cm^2 \cdot h)$ with 0% of biochar content decreased to 0.034 $g/(cm^2 \cdot h)$ with an addition of 4% biochar and increased to 0.037 $g/(cm^2 \cdot h)$ with 8%. The second phase indicated that the crack began to develop and extend greatly, which increased the evaporation surface area. Therefore, there is a sudden increase at the beginning of this stage. In the study of Jin et al. [46], when the biochar content increased to 2% and 4%, there was also a slight increase followed by the constant rapid evaporation stage, and then came the deceleration evaporation stage. Then, a deceleration evaporation process existed in the second half of the fluctuated evaporation phase. Finally, the moisture content stayed stable, which stated a residual evaporation phase with a rate of around 0.5% for these three conditions.

3.2. The Effects of Corn Stalk Biochar on Crack Evolution. During the image processing, the cracking property on the surface of soil samples showed an obvious development process of three-level crack. The development of desiccation crack of soil samples is presented in Figure 2. The cracking on the surface of soil samples is mainly caused by the shrinkage forces produced between soil particles due to constant evaporation of water [47].

The first-level crack is also called the main crack, which developed first during the cracking process. With the evaporation of water, the total volume of the soil sample decreased, the shrinkage force increased between soil particles, and the width of the main crack also increased by the shrinkage force. The main crack that firstly appeared was wide and mainly controlled the whole development of cracking. Then, the second-level crack began to appear from the main crack, with an angle of 90°, like a branch of a tree. The width of the second-level crack is narrower than that of the first-level crack. After continuous evaporation, the soil particles were more condensed and close to each other, where the third-level crack started to develop. The width of the third-level crack was even narrower but still had a cross angle of 90°. The soil samples without biochar content got more third-level cracks, and the width of the main crack was wider than that of soil samples with addition of biochars. It indicated that the biochar particles did not lead to more cracks and even prohibited the evolution of cracking.

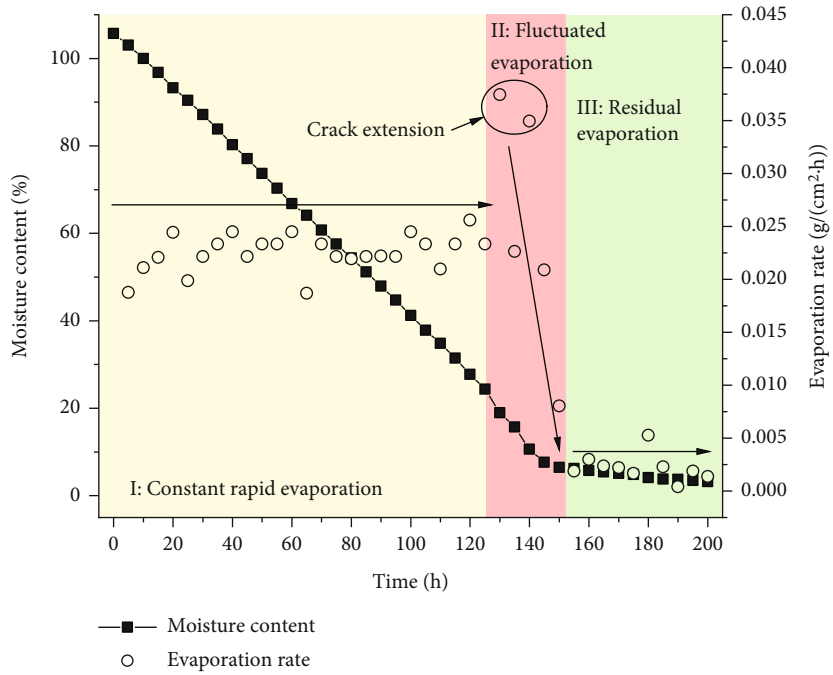


(a) 0% of biochar (original)



(b) 4% of biochar

Figure 1: Continued.



(c) 8% of biochar

Figure 1: Variation of moisture content and evaporation rate of soil samples with different contents of corn stalk biochar.

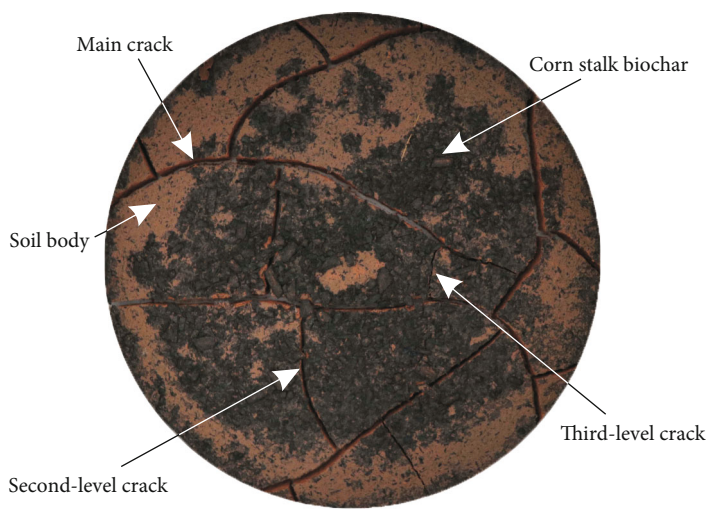


Figure 2: Final development of crack development.

Even though the biochar particles disturbed the integrity of the soil body, it increased the connection of soil particles by forming bridges between them.

The crack ratio can be calculated by Equation (3), which is an important parameter for quantitatively investigating the crack properties.

$$\mu = \frac{A_c}{A} \times 100\%, \tag{3}$$

where μ is the crack ratio of the soil sample (%), A_c is the total area of the cracks (cm^2), and A is the area of the sample container (cm^2).

The value of the final crack ratio and residue moisture content of different additions of biochars are shown in Figure 3. With the increase of biochar contents by weight, the value of residual moisture contents became larger. The residue moisture content of the soil was increased by 105.56% and 88.38% after adding 4% and 8% biochar contents, respectively. The final crack ratio was lowered by 32.39% and 15.31% with the addition of biochar contents of 4% and 8%, respectively. There are more pores

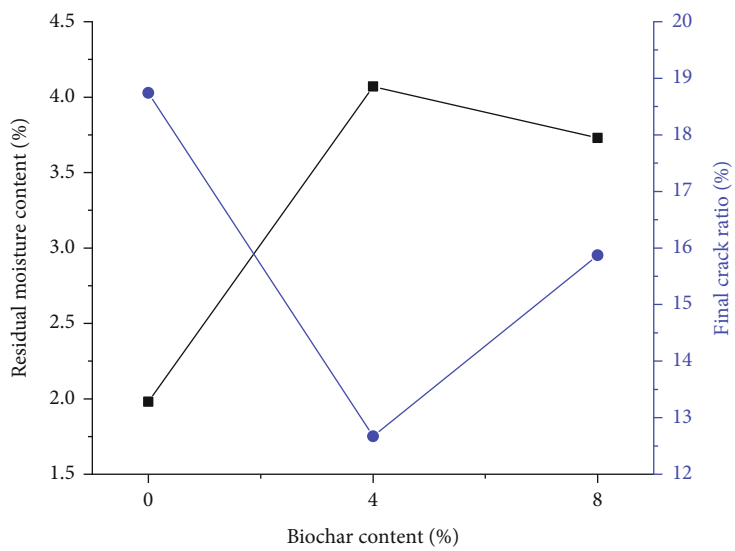


Figure 3: Relationship between residual moisture content, final crack ratio, and biochar contents.

distributing between soil particles and biochar particles, which can store more water [48]. The results indicate that the corn stalk biochar can dramatically improve the water retention capacity and reducing crack development of soil.

4. Conclusion

The influence of corn stalk biochars with contents of 0%, 4%, and 8% on the evolution of evaporation and cracking properties of soils was investigated through free desiccation tests and image treatment. The main conclusions are summarized as follows:

(1) The evolution process of moisture content and the evaporation rate with different biochar contents can be divided into three phases. In the constant rapid evaporation process, free water evaporation contributed the main loss of moisture content. The duration of the fluctuated evaporation phase was shortened with the increase of the biochar content. Only strongly bound water was left contributing to the residue moisture content

(2) The residue moisture content of the soil was increased by 105.56% and 88.38% after adding 4% and 8% biochar contents, respectively. The final crack ratio was lowered by 32.39% and 15.31%, respectively. The results indicate that the corn stalk biochar can dramatically improve the water retention capacity and reduce crack development of soil

(3) A three-level crack was observed during the evaporation process. The second and third crack developed more in soil samples without biochar content than that of soils with biochar contents, which indicated that biochars increased the connection of soil particles

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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