

Research Article

Influence of Vetiver Root System on Mechanical Performance of Expansive Soil: Experimental Studies

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In order to study the influence of the vetiver root system on the swelling characteristics and crack resistance of expansive soil, vetiver grass root growth and its vertical distribution were investigated by the cultivation test and observation. The expansion rate experiment without load and expansive force tests was conducted on planted grass root soil samples, and the effect of the root content on the expansion rate and force of soil mass was analyzed. Finally, the effects of different vetiver contents on the crack resistance of expansive soil were studied by soil cracking experiments in an outdoor natural environment. The results showed that on account of the reinforcement effect of crisscrossing and winding grassroots, the expansion rate and expansive force can be reduced by the grass roots, and the grass roots can significantly increase the anticracking properties of the root-soil composites. From the surface down, the inhibition effect of the vetiver root on the expansive soil appeared from low to high and then decreased; the effect was optimal in the layer of 10~15 cm. Compared with the pure expansive soil, the swelling force of the cultivated root expansive soil growing for 180 d decreased by more than 80%, and the unloaded expansive soil reduced by more than 70%. Compared with pure expansive soil, the swelling force and the unloaded expansion rate of cultivated root expansive soil growing for 90 d decreased by more than 50%.

1. Introduction

Expansive soil is multifractured, also called as “cracked soil,” and cracks have a significant impact on strength index and slope instability [1]. Therefore, the instability mechanism and treatment aspects of expansive soil slopes have been widely studied [2–6]. The existing protection methods are roughly divided into two categories [7]: limiting crack development and not limiting crack development. Not limiting crack methods were directly applied to deal with expansive soils, such as the retaining structure method, slope protection method, geotechnical bag method, and physical improvement method. The main methods for restrictive crack development include the geomembrane method, algorithm change, and chemical improvement method and achieve targeted protection from the perspective of water and particles.

In recent years, more and more scholars paid more attention to the ecological slope protection, and the impact of vegetation on soil cracking has appeared. For example, Li et al. [8] found that short-term rainfall and evaporation process have little effect on the water holding capacity of expansive soil under the vegetation cover. Xie et al. [9] found that erosion occurs on the slope surface, which can be prevented by vegetation due to the interception effect. Larger leaf area and greater root depth can reduce the water content in the soil, contributing to the increase in shear strength. Thereby, vegetation on expansive soil slopes is normally suggested [10–14]. The change in water content is the main reason for the fracture of expansive soil [1]. In addition, their findings indicate that vegetation evaporation could slow down the cracking process of the expansive soil. The distribution of roots in soil is a more complicated problem.

Some scholars have studied the mechanical effects of roots on composite soils and found that the existence of roots could enhance the strength of composites [15–20]. On this basis, Wang et al. [21] show that rice straw can slow the cracking of reinforced soil and declared that the best rate of rice straw is 0.3%. Li [22] believed that plant roots agglomerate soil particles and limit soil cracking. Zhang et al. [23] studied the dry shrinkage of the farmland soil and found that when the root content was larger, the fracture area density was smaller and the fracture length density was larger. Zhou et al. [24] analyzed the strengthening mechanism of the plant root system from the perspective of composite materials and believed that the root fiber played an anticrack strengthening role in the composite materials of root and soil. These results indicate that the reinforced action of rice straw, roots, etc., can improve the structure of the soil and restrict the cracking of the soil.

Because vetiver has a strong vitality and a developed root system, it is commonly used to deal with the slope stability problem [25]. However, little literature has paid attention to its reinforced function. Guo et al. [26] and Bao et al. [27] have discussed the characteristics of vetiver and black locust plants and the technical methods of planting and compared the effects of other methods to control slope collapse and its social and economic benefits and feasibility. The results showed that planting vetiver and hedgehog plants could enhance the slope stability and prevent landslides. Zhou et al. [28] carried out a confined expansion test and a direct shear test on expansive soils with different initial water contents, and the results have shown that the vetiver root system could reduce the expansive force and increase the shear strength. But, the experimental soil sample was a remodeled root-soil complex without considering the effect of actual planting roots on expansive soil.

In summary, most literature studies mainly focus on the general soil quality, and there are few studies which paid attention to the expansion and cracking and shrinkage deformation of expansive soil. Although the use of vetiver and other ecological protection methods to treat expansive soil slope disease has been used more and more, the design and construction are mostly based on the experience of engineers, and there is no theoretical support. Therefore, the research on the influence of the vetiver root system on the swelling characteristics and crack resistance of expansive soil has an important theoretical significance and engineering application value to inhibit the expansion mechanism of expansive soil and dry shrinkage cracking.

2. Experimental Setup

2.1. Test Soil. The soil samples were taken from Changsha Shuxiang Road, Hunan, China. They were passed through a 2 mm sieve. According to the SL237-1999 Geotechnical Test Procedure, the free expansion ratio, maximum dry density, liquid limit water content, plastic limit water content, and the optimum moisture content were determined. The test results are shown in Table 1. According to the JTJ031-95 “Classification of Highway Subgrade Design Code” (China), the soil was classified as weak expansive soil.

2.2. Experimental Design

2.2.1. Vetiver Root System. In order to realistically simulate the actual planting environment, three compaction degrees of 95%, 92%, and 90%, respectively, were chosen. A height of 5 cm was for 1 layer to control compaction degrees. The planted soil was divided into three layers and compacted in a compaction mold with an inner diameter of 19.8 cm. After compaction, the compactness of soil from the bottom to top of the mold was 95%, 92%, and 90%, respectively. Taking 95% compaction as an example, the soil layer height is 5 cm and the water content is 20.5%. Firstly, the required soil quality was calculated, and then the soil was added to compaction molds with a height of 5 cm twice. The rest of the different compaction soil layers are made with reference to this. According to this method, a 15 cm soil column is obtained. Considering that the expansive force is positively correlated with the compactness and the root coefficient decreases with the increase in the buried depth, it is considered that the soil layer with large compaction is close to the surface. When the 15 cm high soil column is taken out from the mold, with the 95% compaction soil layer on the top and the 90% compaction soil layer under the bottom, it is poured into the PVC pipe and then shaved on the upper surface. According to the same upper and lower order, a soil column is placed in the PVC pipe together with the soil column in the pipe spliced into compacted soil with a height of 30 cm (Figure 1), so that the soil layer with high compaction is close to the ground.

In order to keep the vetiver grass alive, a 10 cm height of loose planting soil was added to the surface of the compacted soil, and the planting soil was removed while sampling to retain only the compacted soil. Six seedlings were planted per PVC pipe. As the vetiver roots developed into the compacted soil to form a root-soil complex, 24 sets of samples were prepared according to this method (Figure 2).

2.2.2. Experimental Procedure of Expansive Force for Planted Soil. After 90 days and 180 days, the root-soil complex in the cultivation tube was taken out. The upper stem and leaf parts were cut off and the planting layer was removed. The soil cake was cut into 6 layers, and the height of the layer was 5 cm. To determine the sampling position of the ring knife, the distribution position of the root system in the cross section was observed. The ring cutter has a diameter of 61.8 mm and a height of 20 mm.

According to the Trade Standard of P. R. China (SL237-025 1999), the no-load expansion rate test was carried out. As shown in Figure 3, the instrument was calibrated before testing. Unlike the no-load expansion rate test, the expansive force test replaces the hanging plate with a sand-filled bucket and replaces the weight with iron sand according to the Trade Standard of P. R. China (SL237-027 1999). The expansive force was measured by the equilibrium press method, and it was calculated by weighing the sand with an electronic balance with an accuracy of 0.1 g.

TABLE 1: Basic parameters of the test soil.

Index	Optimum water content (%)	Maximum dry density (g·cm ⁻³)	Free swelling ratio (%)	Plastic limit (%)	Liquid limit (%)	Plastic index
Value	20.5	1.56	50	23.9	53.5	29.6

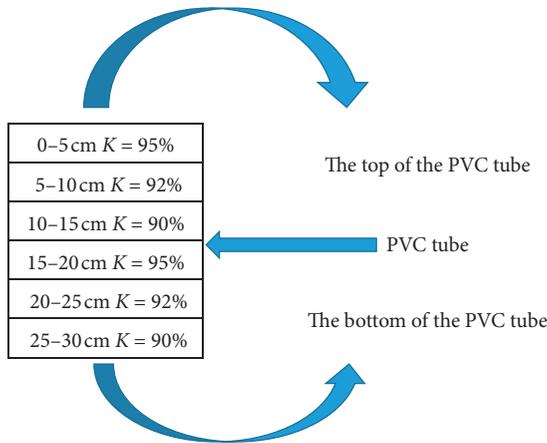


FIGURE 1: Compaction diagram.

For the statistical of the root content, the samples were collected after the end of the test. Then, samples were soaked in clean water for 2~3 h. After the soil was completely disintegrated, the solution was passed through the 0.25 mm sieve. Then, the roots of the filter surface were rinsed with water to obtain the grass roots. The root content was weighed and calculated according to the following formula:

$$\delta = \frac{m}{v}, \tag{1}$$

where δ is the root content, m is the mass of the root, and v is the volume of the soil.

2.2.3. *Experimental Procedure of Dry Shrinkage Cracking for Grafted Soil.* The influence of different root contents on the cracking characteristics of expansive soil was studied by laboratory simulation experiments.

The soil samples were divided into 5 parts with a mass of 4.5 kg each. Four parts of the soil samples were added with 4 parts of the root system, which were 39, 78, 117, and 156, respectively, and then fully mixed. The root system with a length of 50 mm and a diameter of 1 mm was added. Five soil samples were packed into the container with a size of 300 mm × 200 mm × 100 mm, respectively. The sample height was 5 cm and was saturated.

The containers were placed outside for illumination. The samples were observed three times a day, which were at 6 am, 12 noon, and 6 pm. When cracks appeared, the frequency of observation was increased. The parameters were tested including cracking time, crack width (Figure 4), and temperature. When the crack width is greater than 10 mm and there is no change for 6 hours, the observation is stopped.

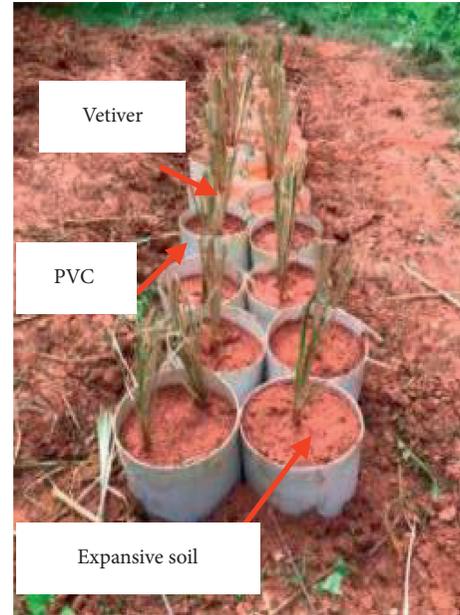


FIGURE 2: Vetiver cultivation.

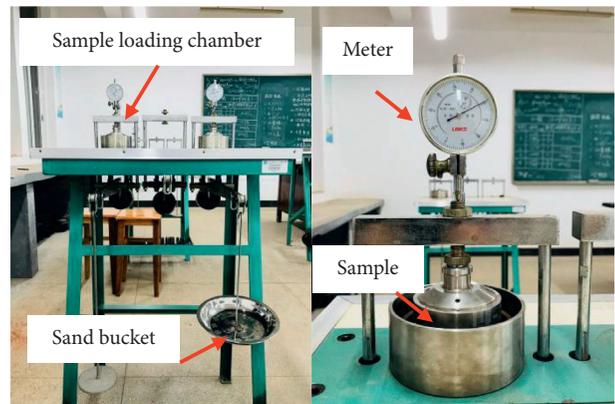


FIGURE 3: Consolidometer and sample loading chamber.

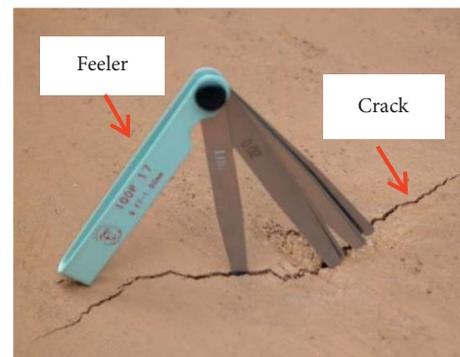


FIGURE 4: Measuring the crack width.

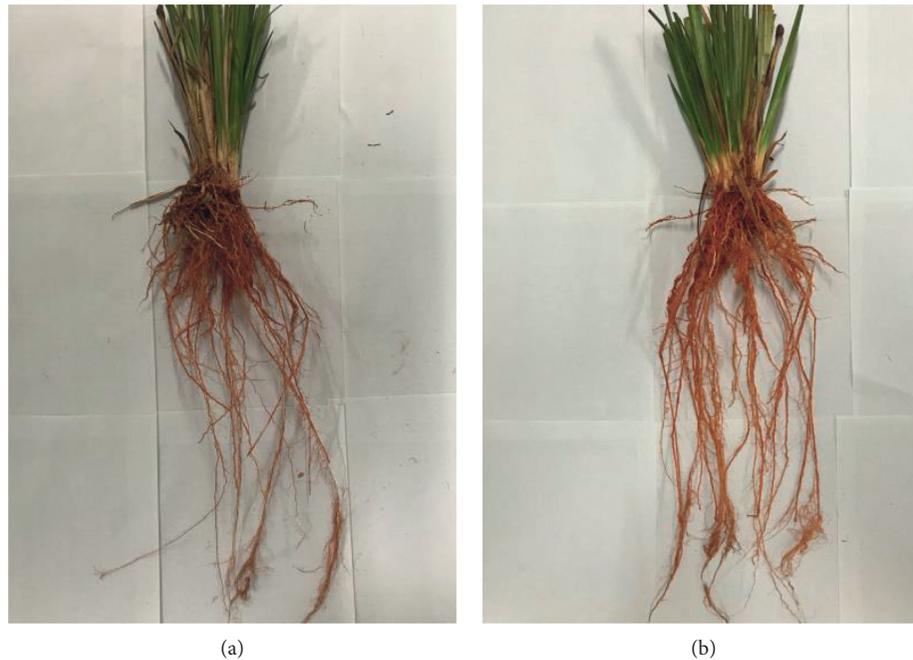


FIGURE 5: Root distribution: (a) 90 d; (b) 180 d.

3. Results and Discussion

3.1. Root Appearance and Growth Distribution. After 90 days and 180 days, the distribution of vetiver growth is shown in Figure 5. The root diameter of 90 d vetiver in the range of 0~20 cm is mostly more than 1 mm, and the root diameter is less than 1 mm in the depth range of 20~30 cm. At the same depth, in the situation of 180 d, the root of vetiver is thicker and denser than that of 90 d. Figure 6 shows that with the increase in the depth of the soil layer, the amount of root coefficient decreases.

3.2. The Influence of Root System on the Expansion Rate of Planted Root-Soil Complex. Figure 7 shows the variations of the no-load expansion rate with time. The development of expansive force can be divided into three stages: water absorption expansion, accelerated expansion, and slow expansion. The root accelerates the expansion potential of the expansive soil during the water-swelling stage. When the expansion potential is released to a certain extent, the root system has an inhibitory effect on the expansion potential.

Figure 7 shows that the no-load expansion ratio of the 180 d root-soil composite is less than that of 90 d in the same depth range, and the no-load expansion ratio of the 90 d and 180 d root-soil composites is smaller than that of the pure soil, indicating that the root system can suppress the expansion ratio. In addition, with the increase in the root content, the ability to inhibit the expansion rate is also improved.

In the situation of 180 d, the no-load expansion rate of root-soil was determined for the depth range of 0~30 cm with 5 cm intervals, compared with that of pure soil, and the maximum no-load expansion rate reduction for soot

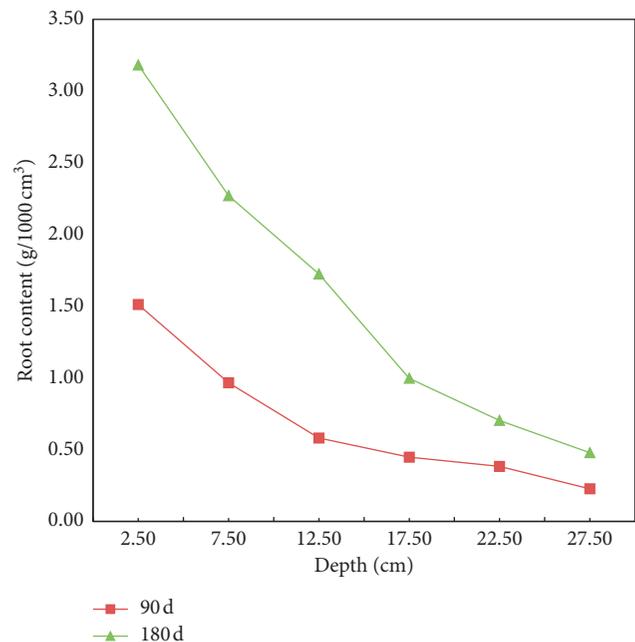


FIGURE 6: Root rate change trend with depth.

soil was 40.9%, 60.6%, 70.9%, 50.8%, 42.7%, and 44.5%, respectively. Meanwhile, in the situation of 90 d, the maximum no-load expansion rate reduction for soot soil was 59.1%, 37%, 56.4%, 29.3%, 27.4%, and 20.9%, respectively.

From the surface of the soil to the bottom, the influence of the inhibition ability of the root system on the expansive soil increased and then decreased, and the best areas of inhibition ability occurred in the height of 10~15 cm.

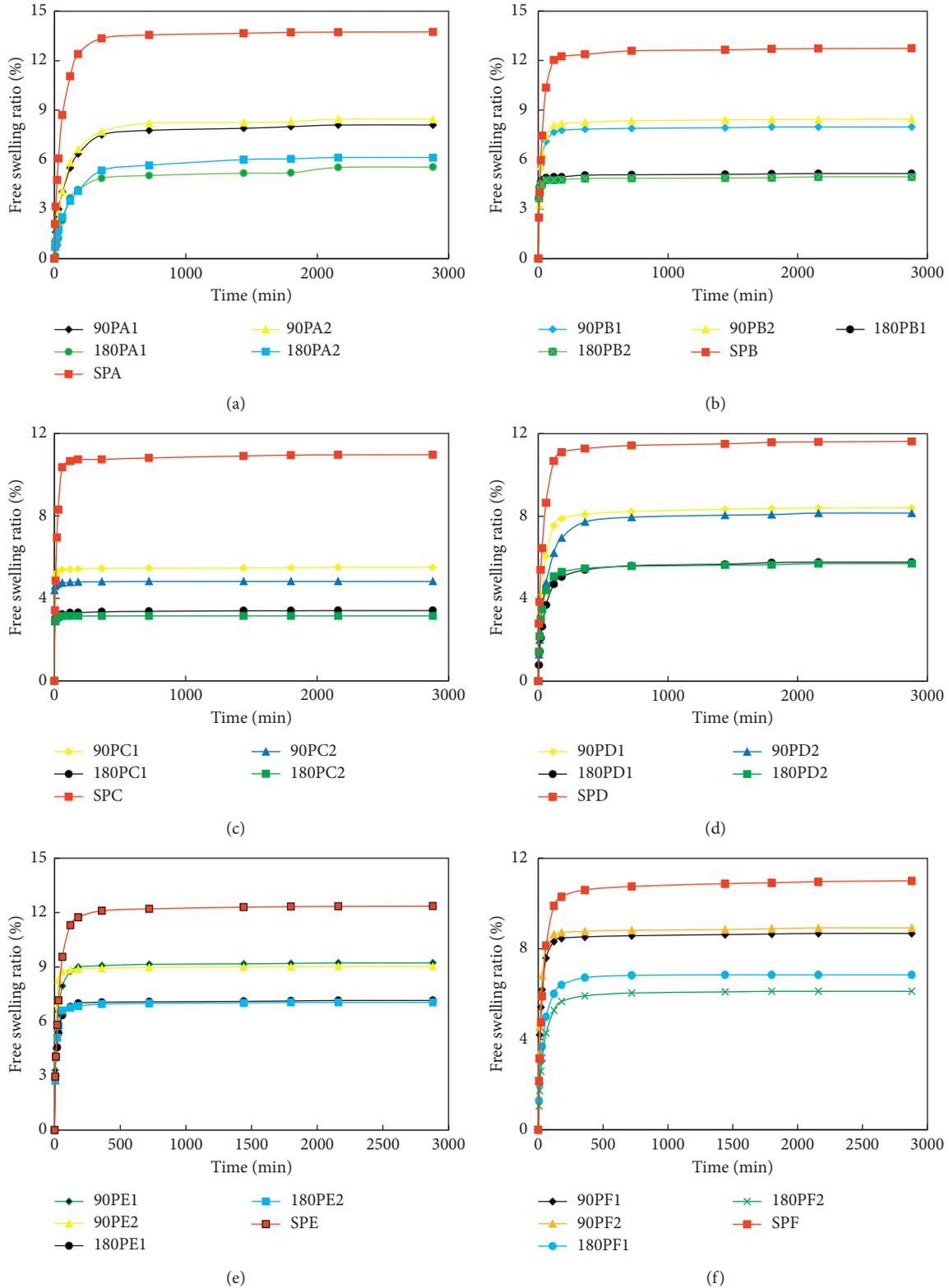


FIGURE 7: The expansion rate of soil in different soil layers varying with time: (a) 0~5 cm; (b) 5~10 cm; (c) 10~15 cm; (d) 15~20 cm; (e) 20~25; (f) 25~30 cm (90 and 180, the growth age; P, the root-soil composite sample; SP, the pure soil sample; a~f, different sampling depths; 1 and 2, the parallel test group number).

Figures 7(a) and 7(d) show that the expansion stability time of the 0~5 cm layer and the 15~20 cm layer root-soil composite is larger than that of pure soil, but the no-load

expansion rate is smaller than that of pure soil. And, the no-load expansion ratio decreases as the root content increases. This indicates that the reinforced effect of the vetiver root

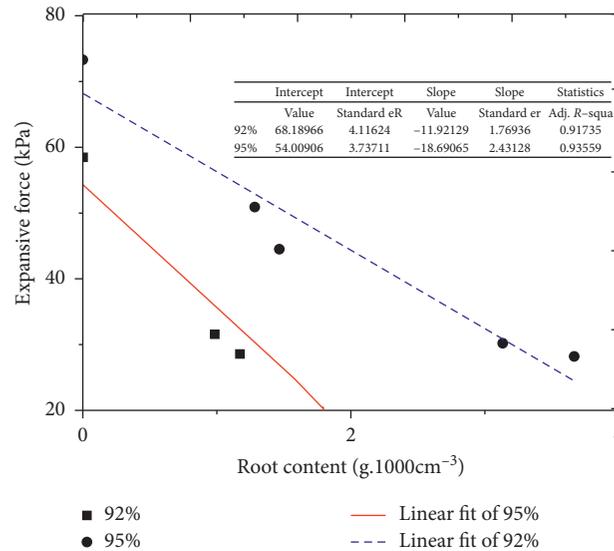


FIGURE 8: Relationship between expansive force and root content.

system can reduce the swelling property of the expansive soil. Due to the high degree of compactness of the two layers of soil samples, the blocking effect of the root system under high density [29] reduced the infiltration, thereby delaying the release of the expansion potential.

Figures 7(c) and 7(f) show that the height of 10~15 cm and 25~30 cm of the root-soil, the no-load expansion rate, and the expansion stability time were smaller than that of the pure soil, indicating that the vetiver root system accelerates the release of the expansion potential. However, this phenomenon is different from the result of the height of 0~5 cm and 15~20 cm of the root-soil. In addition, as the compactness decreased, permeability of the root-soil improved and the completion time shortened; in other words, the expansion stabilization time become shorter.

3.3. The Influence of Root System on the Expansive Force of Planted Root-Soil Complex. Table 2 shows the results of the expansive force test. In the same depth range, the density and the water content of the sample were the same. The results indicated that the number of added roots had a vital effect on the expansive forces of soils.

In Table 2, the swelling force of the rooted soil was determined for the depth range of 0~30 cm with 5 cm intervals, compared with that of the pure soil; in the situation of 90 d, the swelling force rate reduction for the soot soil was 39.3%, 46.2%, 55.6%, 33.4%, 46.8%, and 47.6%, respectively, when compared with that of pure soil samples. In the situation of 180 d, the swelling force rate reduction for the soot soil was 61.4%, 75.8%, 85.4%, 65.7%, and 75.1%, respectively. These results indicated that grass roots could reduce the expansive soil's expansive force. Lei et al. [30] carried out a test to investigate the influence of the hemp fiber on reinforced expansive soil and also verified this phenomenon. It indicates that the mechanism of vetiver root inhibition of expansion is similar to that of the fiber material. In all, the

deformation of the soil is restricted by the wrapping action of the root network, and the friction between the root and the soil interface degrades and inhibits the partial expansive force.

In the same depth, as the root content increased, the expansive force of rooted soil decreased, which indicates that the number of added roots has an obvious impact on the expansive force.

In addition, although the root content of soil under the situation of 180 d was bigger than that of 90 d, for different heights of soil, the expansive force reduction is not the same. Taking 0~5 cm and 25~30 cm layers as an example, in the situation of 90 d, the maximum reduction of expansive force occurred in the height of 25~30 cm, up to 47.6%, and for 180 d, this value was up to 75.1%. The 25~30 cm layer has less root content and abundant fine roots, and its specific surface area is large. With an increase in the contact area in the rooted soil, there is an increase in the ability to reduce expansive force; in other words, as the surface area increased, the ability to inhibit the expansive force also increased.

However, compared to the situation of 180 d, although the root content was bigger than that of 90 d, in the height of 15~20 cm, the reduction rate in expansive force in 90 d was bigger than that of 180 d, and this is due to root-soil; fine roots with similar root mass have more roots and a larger specific surface area; therefore, the effect of fine root reinforcement is better than that of coarse roots with the same root mass.

Meanwhile, the average water content of the layers 0~5 cm and 5~10 cm was 17.02% and 17.58%, respectively, and the water content was similar. The linear fitting of the layer's root content and expansive force, R^2 , was 0.94 and 0.92, respectively, and the linear slope was 18.69 and 11.92, respectively (Figure 8). It is clear that the root system has a significant effect on the inhibition of expansive force under the condition of low density. Under the condition of high compactness, soil particles are closely bound to each other,

TABLE 2: Expansive force test results.

Height	Category	Density (g·cm ⁻³)	Water content (%)	Root content (g/1000 cm ⁻³)	Growth period (d)	Expansive force (kPa)
0~5 cm	Pure soil	1.97	17.0	—	—	73.3
	Root-soil	1.96	17.3	1.467	90	44.5
		1.92	17.2	1.283	90	50.9
		1.95	16.9	3.133	180	30.2
		1.92	16.7	3.667	180	28.2
5~10 cm	Pure soil	1.78	17.6	—	—	58.2
	Root-soil	1.76	17.8	0.983	90	31.3
		1.73	17.8	1.170	90	28.3
		1.78	17.1	2.267	180	14.1
		1.74	17.6	2.083	180	16.6
10~15 cm	Pure soil	1.66	18.6	—	—	26.8
	Root-soil	1.65	18.5	0.583	90	12.0
		1.62	18.2	0.650	90	11.9
		1.63	18.2	1.706	180	3.9
		1.62	18.6	1.467	180	5.1
15~20 cm	Pure soil	1.97	19.5	—	—	62.3
	Root-soil	1.98	19.1	0.444	90	45.2
		1.96	18.8	0.517	90	41.5
		1.97	19.4	0.983	180	21.4
		1.93	18.9	0.867	180	22.6
20~25 cm	Pure soil	1.78	19.7	—	—	53.6
	Root-soil	1.74	19.5	0.383	90	28.5
		1.72	19.8	0.317	90	30.7
		1.77	19.8	0.653	180	19.0
		1.74	20.1	0.517	180	20.5
25~30 cm	Pure soil	1.65	20.8	—	—	23.3
	Root-soil	1.65	20.3	0.217	90	12.2
		1.68	20.5	0.184	90	14.6
		1.67	20.7	0.451	180	7.2
		1.65	21.0	0.434	180	5.8

which hinder the flow of water between particles and reduce the expansive force.

3.4. The Influence of Root System on the Dry Shrinkage Cracking for Grafted Soil. As shown in Figure 9, the maximum crack width on the surface of the sample changes with time. Figure 9 shows that, with the increase in the root content, the maximum crack width decreases and the number of cracks increases slowly, indicating that the root has the effect of inhibiting cracking. To quantitatively describe the inhibition effect of vetiver reinforcement on dry shrinkage cracks in expansive soil, the equation of crack width reduction rate (P_b) was introduced in this paper. P_b is defined as follows:

$$P_b = \frac{(P - P_d) \times 100}{P}, \quad (2)$$

where P is the maximum crack width of the soil sample without vetiver and P_d is the maximum crack width of vetiver reinforced soil.

After calculation, the maximum crack width reduction rate of the expanded soil samples with a root content of 0.78 g/1000 cm³, 1.56 g/1000 cm³, 2.34 g/1000 cm³, and 3.12/1000 cm³ was 9.09%, 77.27%, 88.64%, and 97.73%, respectively. It indicated that the root system of vetiver could inhibit the shrinkage crack

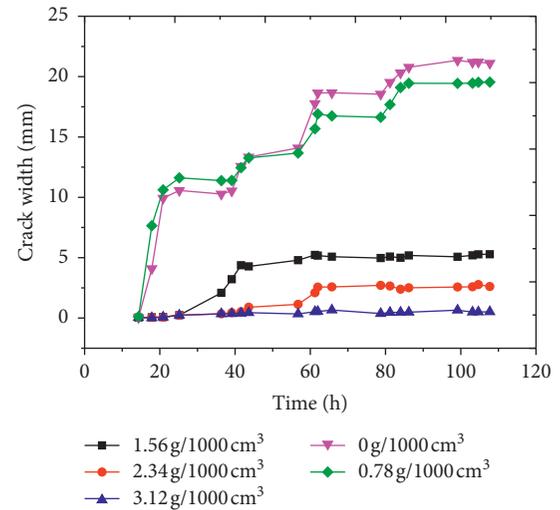


FIGURE 9: Variation of crack width on the surface of the sample.

of expansive soil, and the higher the root content, the more obvious the effect.

Figure 10 shows the shrinkage cracks of rooted soil with different root contents: for no rooted soil and a root content of 0.78 g/1000 cm³. All soils were penetrated from the surface to the bottom, and the samples were divided

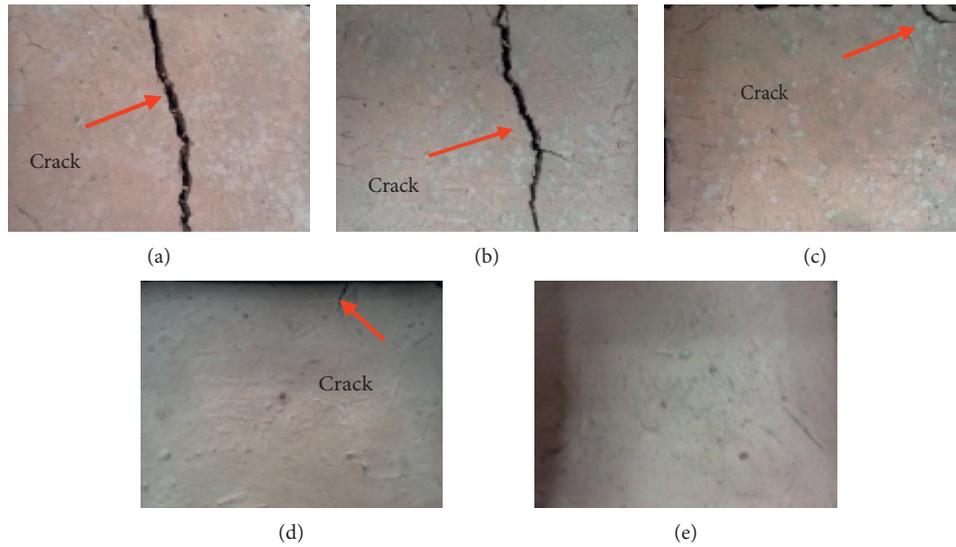


FIGURE 10: Dry shrinkage cracks on the surface of composite root-soil of vetiver roots with different root contents: (a) pure soil; (b) root content is $0.78 \text{ g}/1000 \text{ cm}^3$; (c) root content is $1.56 \text{ g}/1000 \text{ cm}^3$; (d) root content is $2.34 \text{ g}/1000 \text{ cm}^3$; (e) root content is $3.12 \text{ g}/1000 \text{ cm}^3$.

into two parts. As the root content increased, the development of the cracks became decreased and was only found in the shallow surface. Because the inhibition was enhanced by the roots, the development of the cracks is only found in the shallow surface. When the root content was up to $3.12 \text{ g}/1000 \text{ cm}^3$, no obvious cracks appeared on the surface of the sample, and only a small amount of fine cracks was found.

The grafted root system has the effect of inhibiting the cracking of the expansive soil, and within a certain root content range, the greater the root content, the more obvious the effect of inhibiting the cracking, and the actual planted root system should have a stronger inhibitory effect than the grafted root. So, what is the relationship between expansive force or expansion rate and cracking?

3.5. Mechanism of Vegetation Root Inhibiting the Cracking of Expansive Soil

3.5.1. Enhancing Soil Bonding. Due to root interspersed and intertwined from the pores of the soil, which provides a good overall encapsulation effect for the soil particles. As shown in Figure 11, the expansion soil will have a strong interparticle combination, especially the large number of capillary roots derived from the main root system. This function can intersperse and wrap the surrounding soil layer. Thereby, the root greatly increases the shear strength of the soil and improves the tensile strength of the soil and then inhibits cracking. The cohesive force in the shear strength parameters is mainly produced by cementation, which is formed by the long-term geological action of the geotechnical. Once the failure surface is formed during the stress process, the cohesive force would be considered to lose. And, these characteristics are unrecoverable in a short term. Tang et al. [31] pointed out that when the soil is subjected to

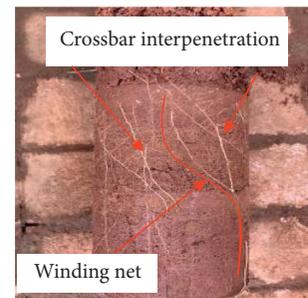


FIGURE 11: Soil wrapped by roots.

tensile force, it would overcome the attraction between the particles and the chemical bonding force, as well as the surface tension and the attractiveness of the water in the soil. Zhang and Chen [32] found that there is a certain correlation between tensile strength and the shear force state of the soil, that is, the tensile strength increases with the increase in cohesion. Zhu et al. [33] found that there is a certain degree of linear correlation between tensile strength and shear strength of unsaturated cohesive soils. Zhu [34], Li [35], and Tang et al. [36] also found similar laws, which showed that the entanglement of the root system improves the soil binding force and also increases the tensile strength of the soil. Thus, tensile strength is one of the key factors which affect soil cracking [1]. When the lateral shrinkage stress is greater than the sum of the tensile strength and the lateral compressive stress caused by the soil self-weight stress, the crack is generated. Because the root system could increase the tensile strength of the expansive soil, the cracking of the expansive soil can be suppressed to some extent.

3.5.2. Reducing the Soil's Expansive Force and Expansion Rate. On the one hand, the action of root wrapping reduces

the expansion of the expansive soil, and on the other hand, it inhibits the expansive force. The root system reduces the expansibility and inhibits the cracking. Liu et al. [37] found that the gray entropy of the crack image on the surface of expansive soil increases with the increase in the expansion rate, and the larger the gray entropy, the greater the degree of crack development. At the same time, this research also found that the greater the expansion, the lower the strength of the expansive soil and the lower the strength. The expansive soil was more susceptible to cracking when the soil strength was low. Liu et al. [38] found that the ultimate fracture development of expansive soil is limited by load and is related to its own expansive force. The larger the expansive force, the larger the average length of the unit crack. The root system can reduce expansive force and unit crack length. Thereby, the soil cracking would be inhibited to a certain extent.

3.5.3. Extrusion of the Root System. The growth of the root system is from fine to thick, and this process will make the surrounding soil extruded. When the roots grow, the axial force generated by the root tip to the surrounding soil expands in a cylinder behind the root tip and is a kind of pressure [39]. Under the constraint of the confinement, fitting makes the expansive soil more compact. Liu et al. [40] showed that the greater the initial compaction degree, the smaller the fracture rate and total crack length of the expansive soil.

3.5.4. Atmosphere-Vegetation-Soil Interaction. Wu [41] showed that plant transpiration could increase soil suction, which would reduce the soil permeability coefficient and increase shear strength. After 20 days of the transpiration test, it was found that the maximum suction force in the grass vegetation soil could reach 1.3 times than that of the bare soil, which also increased the shear strength of the soil by about 30%. At the same time, the suction effect of grass vegetation soil can reach more than three times in the depth of grass roots. The relationship between shear strength and cracking has been explained in Section 3.5.1. It is clear that the transpiration inhibits the cracking of expansive soil. This result also showed that the actual root system has a more obvious effect on the inhibition of expansion cracking.

4. Conclusions

- (1) The wrapping action of vegetation roots can significantly reduce the expansion rate and expansive force of expansive soil. Under the conditions of this experiment, the expansive force of planting root expansive soil growing for 180 d and 90 d decreased by 85.4% and 55.6%, respectively, compared with that of plain expansive soil, and the no-load expansion rate decreased by 70.9% and 59.1%, respectively.
- (2) The higher the root content of vetiver root and the lower the compactness of expansive soil, the more obvious the effect of the root to restrain the

expansion rate and reduce the expansive force. Under the same root content, the effect of fine roots on the inhibition of expansion can reach 75.1%, and it was better than that of coarse roots which can reach 33.4%. In the soil with high compactness, the root system could delay the release of the expansion potential. However, in the soil with low compactness, the root system could accelerate the release of the expansion potential.

- (3) The maximum crack width reduction rate of the expansive soil samples with a root content of 0.78 g/1000 cm³, 1.56 g/1000 cm³, 2.34 g/1000 cm³, and 3.12/1000 cm³ was 9.09%, 77.27%, 88.64%, and 97.73%, respectively. The effect of the vetiver root on inhibiting dry shrinkage cracking of expansive soil is more obvious with the increase in the root content.
- (4) In this study, when the root content is increased to 3.12 g/1000 cm³, the expansive soil will no longer crack. Considering the transpiration of vegetation, the inhibition of planting roots on the cracking of expansive soil will be more obvious.
- (5) From the surface down, the inhibition effect of the vetiver root on the expansive soil appeared from low to high and then decreased; the effect was optimal in the layer of 10~15 cm.

The reinforcement effect of the actual root system is not only related to root diameter and root content, but also related to root distribution direction, root quality, root length, and so on. These factors not considered in this paper need further research in the future.

Data Availability

All data included in this study are available upon request by contacting the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

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