Moisture Characteristics of Improved Gravelly Guest Soil for Bio-slope-engineering

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Research Article

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Abstract

This paper explores the reasonable proportion of guest soil in bio-slope-engineering by means of proportional experiments. In the experiment, rubble and improved materials such as peat and water-retaining agent were selected to study the effect of peat and water-retaining agent content on moisture constant, permeability coefficient and water absorption rate of guest soil.The measurements showed that peat and absorbent agent improve effective water capacity and water absorption speed of guest soil, thus guest soil absorb and hold more effective water; however, with the increase of peat content, wilting moisture capacity of guest soil will increase and its permeability coefficient will also enlarge, which is a disadvantage to plants survival in drought conditions and slope stability in rainy seasons. According to guest soil's proportional experiments and field test, the favorable amount of rubble, peat, absorbent agent and aggregate agent, is 80%, 20%, 1.0‰ and 1.0‰, respectively, and the reasonable content of fertilizer in guest soil is 100 g/m2. The results may guide the design and construction of Guest soil spraying for bio- slope-engineering.

1. Introduction

Bio-slope-engineering is a new technology to stabilize geotechnical slope and beautify ecological environment by using the principle of vegetation water conservation and soil consolidation (Zhou and Zhang 2003). Simultaneously, this technology has been widely used in highway, railway, hydropower, municipal engineering slope protection and vegetation restoration at present (Ciabocco et al. 2009; Cochard et al. 1996; Harianto et al. 2008; Karina and Havana 1999; Zhang et al. 2000). The application of vegetation slope protection is based on the stable growth and reproduction of slope plants, which actually needs to solve the problems in two aspects. First, the slope plants design of selection and combination should be reasonable and scientific. Second, it is necessary to artificially create a suitable soil environment for plant growth on the slope. For the cutting slope formed by engineering excavation, especially in the rock slope, the soil environment of the slope is very poor or almost non-existent. Therefore, it is difficult for plants to settle and reproduce on the cutting slope formed by excavation. To solve this problem, based on the advanced experience of vegetation slope protection, the researchers have developed slope soil improvement techniques (Xu et al. 2013; Zhang 2001; Wang et al. 2003; Kim and Park 2016; Kim et al. 2017; Chen et al. 2013;). The new technology of spraying and mixing greening has been widely used in the greening of rock slopes (Zhang et al. 2000). Additives in the soil have been proved to be beneficial to plant growth in the mixture (Harianto et al. 2008). The industrial by-products (Kim and Park 2016) and other organic compounds (Kim et al. 2017) have been used as vegetation concrete fillers, which get great effect. Additionally, Chen et al. (2013) proved that when the content of concrete was 4%, the germination rate of vegetation seeds was the highest.

The properties of erosion resistance, shrinkage recovery, fertility and mechanics of the improved guest soil were deeply studied (Zhang and Zhou 2002; Zhang and Zhou 2004; Li et al. 2006; Wang et al. 2010; Zhang et al. 2003; Xia et al. 2011; Katuwal et al. 2011). Some studies proved that plant roots impacted soil cohesion (Katuwal et al. 2011), and reduced erosion resistance coupled with the influence of colonies

(Cui and Caldwell 1996; Baets and Poesen 2010). The decrease in soil erosion resistance causes precipitation's damage to guest soil and soil loss, but reasonable selection of the composition of base material mixture can improve the corrosion resistance of guest soil (Zhang and Zhou 2002). However, the base material mixtures contain a certain amount of organic matter, and the organic matter has the property of shrinkage and recovery with the change of water content. Not expected, the excessive shrinkage of the substrate mixture can produce more cracks, which is not conducive to the growth and development of plants (Zhang and Zhou 2004; Correa et al. 2019). The addition of straw fiber (Li et al. 2006) can enhance the shear strength of the base material mixture, delay the period of shrinkage and reduce the crack width. The base material (Zhang et al. 2003; Xia et al. 2011) and plant root system (Abdi et al. 2014; Ghestem et al. 2014; Tardio and Slobodan 2015; Endo and Tsuruta 1969; Ziemer 1981) improve the shear strength of guest soil effectively, and the strength of guest soil has an important influence on the stability of guest soil in the slope.

For the growth of slope plants, the moisture in guest soil is a key factor (Li et al. 2006; Wang et al. 2010; Dekker et al. 2001). Unlike urban landscaping, the management of vegetation slope protection is considered extensive, so the water needed for the growth and reproduction of slope plants mainly comes from atmospheric precipitation. The characters of vegetation slope protection require that the improved guest soil should have good properties such as water absorption, water storage, water retention (Zhang et al. 2005). According to the on-site monitoring and test analysis, the long-term protection effect of many vegetation slope protection projects is not ideal. One of the reasons for the rapid decline of plants is that the moisture parameters of the improved guest soil on the slope can not meet the needs of plant growth. The density of the jetted guest soil makes it difficult for the rainfall to infiltrate quickly, and the water absorption rate of the guest soil is slow. The plant-soil-water interaction also determines the slope stability of vegetation cover (Bordoloi and Ng 2020; Ali et al. 2012), water absorption efficiency (Cochard et al. 1996; Das et al. 2017), and growth of plants (Das et al. 2018; Doussan et al. 2006).

At present, improved guest soil has been widely used in vegetation slope protection. However, in the absence of the study on the water characteristics of guest soil for vegetation slope protection , it is impossible to obtain the reasonable proportion of guest soil. Moreover, the guest soil used in these researches is suitable for plant growth (Zhang et al. 2005), this kind of guest soil is difficult to meet the needs of engineering in mountainous areas. In the actual vegetation slope protection engineering, the guest soil is more in-situ selection of excavated rubble, sand and other inferior soil. Therefore, rubble, formed by slope excavation, and improved materials, such as organic matter and water-retaining agent are selected to carry out proportioning test. The effect of organic matter and water-retaining agent content on the field capacity, wilting capacity, effective water holding capacity, permeability coefficient and water absorption rate of the improved guest soil were studied. This research may provide preference for the preparation of vegetation slope protection improved macadam soil.

2. Materials And Methodology

2.1. Test main materials

In this study, the main materials of the guest soil were rubble, organic matter, water-retaining agent, granule agent, fertilizer and grass species. The rubble was made of weathered mud and shale crushed from the cutting slope, with a maximum particle size of 4 mm, 50% of 2~4 mm, 20% of 0.5~2 mm, 5% of 0.25~0.5 mm, 25% of the rest. The dry weight was 14.6 kN/m^3 under slight pressure. The organic matter was the peat taken from Xichang City. The peat has many pores, loose structure, large compression and small weight, and the dry weight of the peat was only 1.6 kN/m^3, and 3 times of water absorption. The peat's function was to improve the physical structure of guest soil, store part of water, and provide long-term nutrients for plant growth. In the experiment, the granular polyacrylate absorbent resin was used as the water-retaining agent, and its water absorption ratio was 400 times. The function of the water-retaining agent was to store and slowly release the water needed for plant growth. Polyacrylamide was used as an agglomerate with a molecular weight of 6 million. The function of agglomerate was to promote the formation of guest soil aggregate structure, which was beneficial to the growth of plants. Compound fertilizer with 45% available nutrients was used in this experiment, in which the ratio of $N:P_2O_5:K_2O$ was 15:15:15. The function of fertilizer was to provide quick-acting nutrients for plant growth. The grass species used was C. dactylon, and the germination rate was 95%.

2.2. The proportion of guest soil

Table 1 Proportion of guest soil (volume ratio)

Proportion number	*Gravel soil/%*	*Peat /%*	*Water-retaining agent / ‰*	*Proportion number*	*Gravel soil/%*	*Peat /%*	*Water-retaining agent / ‰*
1	100	0	0	16	70	30	1.0
2	90	10	0	17	60	40	1.0
3	80	20	0	18	50	50	1.0
4	70	30	0	19	100	0	1.5
5	60	40	0	20	90	10	1.5
6	50	50	0	21	80	20	1.5
7	100	0	0.5	22	70	30	1.5
8	90	10	0.5	23	60	40	1.5
9	80	20	0.5	24	50	50	1.5
10	70	30	0.5	25	100	0	2.0
11	60	40	0.5	26	90	10	2.0
12	50	50	0.5	27	80	20	2.0
13	100	0	1.0	28	70	30	2.0
14	90	10	1.0	29	60	40	2.0
15	80	20	1.0	30	50	50	2.0

The proportioning design test of guest soil was carried out in 30 groups (Table 1). The dosage of granule, fertilizer and grass seed in each group was 1.0‰ (volume ratio), 100 g/m^2 and 6 g/m^2, respectively. The rubble was evenly mixed with additional materials such as peat, water-retaining agent, granule and fertilizer, filled in a container with a plane size of 0.44 m × 0.33 m, filled with a thickness of 10 cm and properly compacted, and then the grass seeds were evenly sowed on the surface of the guest soil layer and watered for maintenance.

2.3. Testing method

The field capacity, wilting capacity, effective capacity and permeability coefficient of guest soil were carried out according to the provisions of "*determination of forest soil moisture-physical properties*" (LY/T 1215-1999), "*determination of stable wilting water content of forest soil*" (LY/T 1217-1999) and "*determination of forest soil percolation rate*" (LY/T 1218-1999) (Forest soil analysis method 2000). The guest soil was sampled twice after it was placed in the container, the first sampling was one week later, and the second sampling was two months later. The two samples represented the guest soil before plant growth and when plant growth was exuberant, respectively. The specification of sampling ring knife was

Φ 50.46 mm × 50 mm, and three groups of soil samples were taken for each ratio, and their average values were analyzed.

3. Results And Discussion

3.1. Moisture constant of guest soil

For water constants such as field capacity, wilting capacity and available capacity, the percentage of mass (g/g) commonly used in soil science is expressed. However, for the improved guest soil of vegetation slope protection, the mass percentage can't directly reflect the water content of guest soil because of the large difference in dry density between guest soil with different proportions. In contrast, the volume percentage (cm/cm^3) used to express the field capacity, wilting capacity and effective water capacity of guest soil can make the moisture constants of guest soils with different proportions are comparable.

To eliminate the effect of water-retaining agent on the water constant of guest soil, the water constant took the average value of different water-retaining agent content under the same peat content.

Moisture constant test of guest soil proved the field capacity of guest soil increased with the increase of peat content, which was beneficial to store more water for plants (Fig. 1(a)), and the wilting water holding capacity of guest soil increased with the increase of peat content (Fig. 1(b)), but wilting water holding capacity was the lower limit of guest soil water content that can be utilized by plants, so the increase of wilting water holding capacity was not conducive to providing more available water for plants.

Field capacity is the maximum content of capillary suspended water that can be maintained by guest soil, and it is generally regarded as the upper limit of water available to plants in guest soil. Therefore, the range of available water of guest soil was the water content from field capacity to wilting capacity, and the difference between them was the effective capacity of guest soil. As seen in Fig. 1, the absolute value of wilting capacity showed a lower increase when compared to the field capacity with the increase in the peat soil content. The peat content increased from 0 to 50%, the wilting capacity only increased from 3.7% to 5.9%, and the field capacity of guest soil increased from 38.0% to 52.2% after one week. Therefore, the effective water holding capacity of guest soil increased with the increase of peat content (Fig. 2). Meanwhile,the small moisture constant of guest soil measured after 2 months was due to the gradual compaction of guest soil (Fig. 1(a) and 1(b)).

Fig. 3(a) and 3(b) show the relationship between field capacity and wilting capacity of guest soil and the content of water-retaining agent, respectively. To eliminate the effect of peat on the water constant of guest soil, the water constant took the average value of the water constant of different peat content under the condition of the same water-retaining agent content.

The field capacity of guest soil increased with the increase of water-retaining agent content, but compared with the effect of peat, the effect of water-retaining agent is smaller (Fig. 3(a)). For example, the content of water-retaining agent increased from 0 to 2.0 ‰, after 2 months, the field capacity of guest soil increased from 38.8% to 42.2%, an increase of 3.4%. When the content of peat increased from 0 to 50%, the field capacity increased from 35.6% to 49.0%, an increase of 13.4%. While the cost of the water-retaining agent needed to meet this requirement was more than 10 times that of peat.

When the water-holding capacity of guest soil increased from 0 to 2.0 ‰, the wilting water-holding capacity decreased from 5.4% to 4.1% (Fig. 3(b)). The decrease of wilting water holding capacity is beneficial to provide more available water for plants. With the increase of the content of water-retaining agent, the field capacity of guest soil showed an increasing trend, while the wilting capacity of guest soil showed a downward trend, so the effective water capacity of guest soil was bound to show an increasing trend (Fig. 4)..

3.2 Permeability of guest soil

The permeability coefficient of guest soil is an index that comprehensively reflects the permeability of guest soil. When the permeability coefficient is too large, a large amount of rain water infiltrates into the slope during rainfall, which aggravates the instability of the shallow layer of the slope. In contrast, it is very difficult for rain water to infiltrate the guest soil and slope during rainfall when the permeability coefficient is too small, most of Rain Water is lost along the slope. If the permeability coefficient is extremely tiny, even if the artificial watering is used frequently, the seedlings of slope plants often grow poorly or die due to lack of water. Therefore, it is very important to choose a reasonable permeability coefficient of guest soil.

Fig. 5 shows the relationship between the permeability coefficient of guest soil and peat content. To eliminate the influence of water-retaining agent on the permeability coefficient of guest soil, the permeability coefficient is the average of the permeability coefficient of different water-retaining agent content under the same peat content.

When the peat content was less than 10%, the permeability coefficient of guest soil was relatively small, and the permeability coefficient of guest soil measured one week later was $0.13 \times 10^{-6} \sim 0.26 \times 10^{-6}$ m/s; when the peat content was 20% ~ 40%, the permeability coefficient of guest soil changed little, and the permeability coefficient of guest soil measured one week later was $0.79 \times 10^{-6} \sim 1.07 \times 10^{-6}$ m/s (Fig. 5). When the peat content was more than 40%, the permeability coefficient of guest soil increased rapidly. When the peat content was 50%, the permeability coefficient of guest soil increased to 1.89×10^{-6} m/s one week later, an increase of 77%. The excessive permeability coefficient of the guest soil makes the water quickly infiltrate into the slope under the guest soil, which is not conducive to the stability of the slope, so the content of peat in the guest soil should not exceed 40% (Fig. 5).

Fig. 6 shows the relationship between the permeability coefficient of guest soil and the content of water-retaining agent. To eliminate the effect of peat on the permeability coefficient of guest soil, the permeability coefficient is taken as the average value of the permeability coefficient of different peat content under the condition of the same water-retaining agent content.

The permeability coefficient of guest soil decreased with the increase of the content of water-retaining agent (Fig. 6). After the water-retaining agent absorbed water, the water adhered to the water-retaining agent and becomes non-flowing water, which reduced the void ratio of guest soil to a certain extent. Due to the above reasons, the permeability coefficient of guest soil decreased with the increase of the content of water-retaining agent, but the decrease was relatively small compared with the effect of peat. The water content of water-retaining agent increased from 0 to 2.0‰, and the permeability coefficient of guest soil decreased from 0.95×10^{-6} m/s to 0.80×10^{-6} m after one week, with a decrease ratio of 16%.

3.3 Water absorption rate of guest soil

The speed of water absorption is an important index for guest soil. If the speed of water absorption is excessively low, and in the case of short rainfall duration and small rainfall, the guest soil can't absorb enough water to ensure the growth of plants. The water absorption speed of guest soil is defined as the amount of water absorbed by guest soil per unit volume in unit time. The relation curve between water absorption saturation and absorption time can be used to reflect the water absorption speed of guest soil. The definition of the water absorption saturation of guest soil = the water absorption of guest soil / the water absorption of guest soil at saturation × 100%, and the water absorption of guest soil at saturation is taken as the maximum water absorption of guest soil at the end of the immersion test.

Fig. 7(a) shows the curve of water absorption saturation of guest soil with different peat content with time. To eliminate the effect of water-retaining agent on guest soil water absorption saturation, the average value of water absorption saturation of different water-retaining agent content under the same peat content was taken as the water absorption saturation of guest soil. Fig. 7(b) shows the curve of water absorption saturation of guest soil with different water-retaining agent content with time. To eliminate the effect of peat on water absorption saturation of guest soil, the average water absorption saturation of different peat content under the condition of the same water-retaining agent content was taken as the water absorption saturation of guest soil.

The higher the peat content, the faster the guest soil absorbs water. When the peat content exceeds 10%, the water absorption saturation of the guest soil exceeded 95% in the 30min; when the peat content exceeded 40%, the water absorption saturation of the guest soil exceeded 95% in the 20 min (Fig. 7(a)).

As shown in Fig. 7(b), the higher the content of water-retaining agent was, the faster the water absorption rate of guest soil was. When the content of water-retaining agent exceeded 0.5‰, the water absorption saturation of guest soil exceeded 95% in the time of 30min; when the content of water-retaining agent exceeded 1.5 ‰, the water absorption saturation of guest soil exceeded 95% in 20min.

3.4 Reasonable ratio of guest soil

Based on the results of the guest-soil ratio test, from the point of view of improving the effective water holding capacity of the guest soil, it is beneficial to add peat and water-retaining agent to the guest soil (Fig. 1(a) and 1(b)); from the point of the reasonable permeability coefficient of the guest soil, the content of peat in the guest soil should be 20%-40% (Fig. 5); from the point of improving the water absorption rate of guest soil, the peat content in guest soil should not be less than 10% (Fig. 7(a)), and the content of water-retaining agent should not be less than 0.5‰ (Fig. 7(b)).

The reasonable ratio of guest soil involves economic factors in addition to the above technical factors. The addition of peat and water-retaining agent to guest soil can improve its effective water holding capacity, but the water absorption and storage capacity of peat and water-retaining agent in guest soil can not be brought into full play.

According to the water absorption test of peat and water-retaining agent, the peat absorbed 5 times as much water as peat itself, and the water-retaining agent absorbed 65 times as much water as water-retaining agent itself. While the peat and water-retaining agent added in the proportion test, due to the restriction of guest soil particles, its water absorption capacity was only partially brought into full play.

The definition of the water absorption efficiency of peat (or water-retaining agent) is the water absorption of peat (or water-retaining agent) in guest soil / the water absorption of peat (or water-retaining agent) × 100%. The relationship between the water absorption efficiency and improved materials content is shown in Fig. 8.

When the peat content was 20% to 30%, the water absorption efficiency of peat was the highest, and was 60.4% to 63.2% (Fig. 8). Therefore, considering the water absorption efficiency of peat soil, the suitable amount of peat soil in guest soil is 20%~30%. The water-absorbing efficiency of the water-retaining agent was the highest, at 75.6%, when the water-retaining agent content was 1.0‰ (Fig. 8). With the increase of the water-retaining agent content in the guest soil, the performance efficiency of the water-retaining agent decreased. Therefore, considering the water-absorbing efficiency of the water-retaining agent, the suitable dosage of water-retaining agent in guest soil is 1.0‰.

Considering the water constant, permeability coefficient, water absorption rate of guest soil and the water absorption efficiency of peat and water-retaining agent, it is suggested that the reasonable ratio of improved macadam soil is 80% of rubble, 20% of peat, 1.0‰ of water-retaining agent, 1.0‰ of aggregate agent and 100 g/m^2 of fertilizer.

3.5 Monitoring of field spray seeding test

3.5.1 Field spray seeding test

The field test site was located in the DK533+335~DK536+470 section of the Zhanyi-Kunming railway, which belongs to the hilly denudation landform of the Yunnan-Guizhou Plateau, and the line runs along the edge of the U-shaped valley of Huangniwan. The slope bedrock is mainly composed of peat and shale of the Upper Silurian Guandi formation (S3G), which is a weak water-bearing stratum with only a small amount of bedrock fissure water, and the slope residual clayey soil contains a little pore phreatic water. The surface water is mainly seasonal gully water, and the amount of water varies with the season.

The climate of this area is Yunnan plateau monsoon climate, and annual rainfall is 991.5~1200 mm. Land surface evaporation is above 635 mm, and is large. Dry and wet seasons are distinct, and winter and spring are dry and windy. In contrast, summer and autumn rainfall is concentrated, and 80% to 90% of rainfall is concentrated in the rainy season from May to October. In particular in June to August, the precipitation is the most, accounting for about 60% of the annual precipitation. The average annual sunshine is more than 2100 h, so this area is classified as the area of long sunshine.

Among 29 rock cutting slopes in the test section, 20 slopes were selected as guest-soil spray seeding test sites. The slope rate was 1：0.75~1：1, and the total test area was 26696 m^2. The ratio of guest to soil was suggested according to the proportion test, and the slope plants adopted the combination of grass and irrigation dominated by Bermudagrass, grass seed spray sowed and shrub seedling transplaned. The construction technology of the field test was as follows: cleaning, leveling slope→drilling→installating anchor→laying and fixing barbed wire →mixing guest soil→spraying guest soil→ planting shrub seedlings →Prophase maintenance. Fig. 9 shows the photograph of the spray seeding test on the spot.

3.5.2 Test and analysis of moisture characteristics of guest soil

Within 3 ~ 6 months after the completion of the guest soil spray seeding experiment, when the slope was completely covered by plants and the plants grew well, the field capacity, permeability coefficient and water absorption rate of the guest soil in the field test were sampled and tested (Fig. 10, Fig. 11, Fig. 12).

The field capacity of guest soil in the field test was 28.1% ~ 36.8%, with an average of 31.9%, which was 23% lower than that of 41.5% (Fig. 10). The permeability coefficient of guest soil was 0.38 × 10^{-6} m/s ~ 0.66 × 10^{-6} m/s, with an average of 0.49 × 10^{-6} m/s, which was 27% lower than that of mixed test soil (Fig. 11). Compared with the results of the proportioning test, the water absorption rate of the guest soil in the field test was also reduced, and it took nearly 50 min to reach 95% water saturation, which was about 15 min longer than the ratio test (Fig. 12).

In the field test, the concrete injector was used to spray the guest soil to the slope under the action of compressed air, which made the guest soil sprayed on the slope more dense. The water absorption capacity of peat and water-retaining agent can not be brought into full play in dense soil, so the field capacity, permeability coefficient and water absorption rate of guest soil in the field test were lower than the results of the proportioning test.

Even so, the guest soil tested in the field can still ensure the normal growth and reproduction of plants on the rock cutting slope. In the past seven years, the plants on the experimental slope still grow well, and a stable and diverse plant community was gradually formed. Fig. 13 shows the plant growth status of the slope taken in autumn 4 years after the completion of the DK535+824~DK535+990 slope.

4. Conclusions

(1) The addition of peat to gravel guest soil can improve the field water capacity and water absorption rate of guest soil, and make the guest soil absorb and store more water in a short time, but with the increase of peat content, the wilting capacity of guest soil is also increased. This is not conducive to the survival of plants under the condition of drought and water shortage, and too high peat content will significantly increase the permeability coefficient of guest soil, which is not conducive to the stability of the slope.

(2) The addition of water-retaining agent to gravel guest soil also helps to increase the field capacity and water absorption rate of guest soil, and reduce the wilting capacity of guest soil, which is beneficial to make guest soil absorb and store more water in a short time.

(3) The results of field spray sowing test of guest soil show that, considering the water constant, permeability coefficient, water absorption rate of guest soil and the water absorption efficiency of peat and water-retaining agent, the proportion of improved macadam soil is 80% of gravel soil, 20% of peat, 1.0 ‰ of water-retaining agent, 1.0 ‰ of aggregate agent and 100g/m2 of fertilizer is reasonable.

Declarations

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Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figures

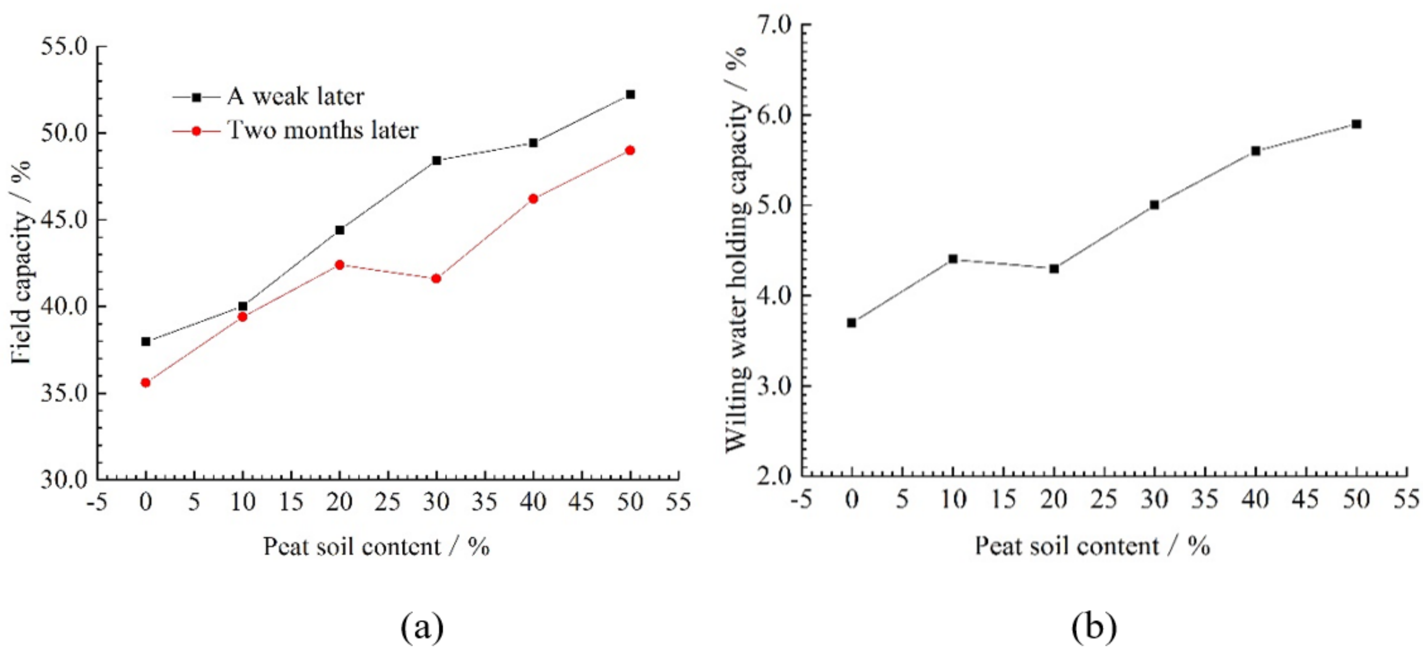

Figure 1

Relationship of moisture constants of guest soil and peat content

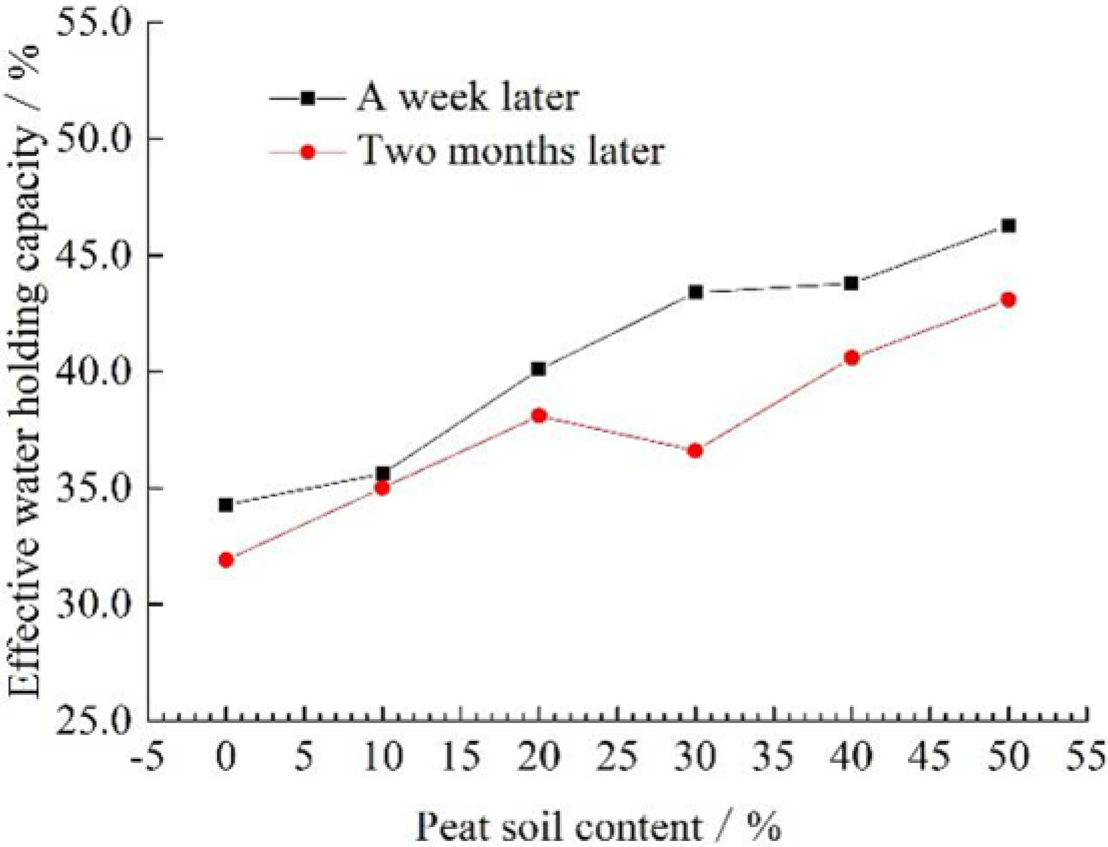

Figure 2

Relationship of effective water capacity of guest soil and peat content

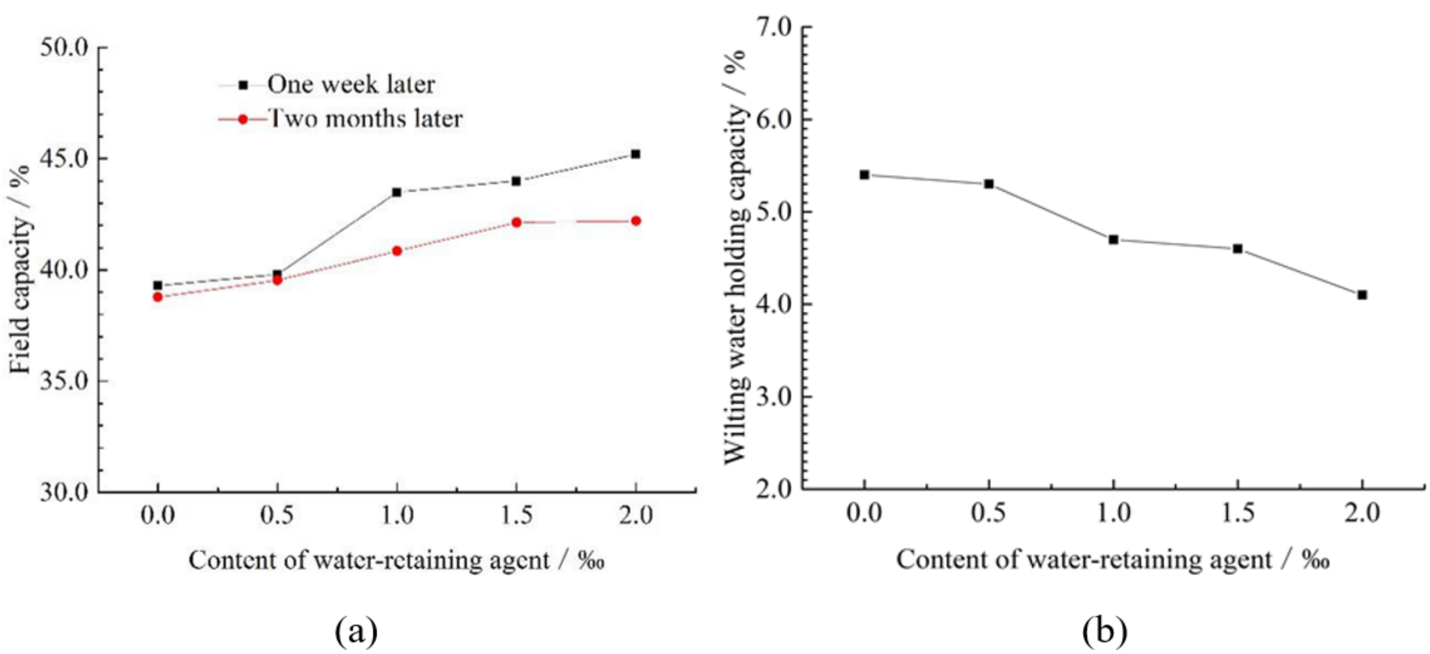

Figure 3

Relationship of moisture constants of guest soil and absorbent agent content

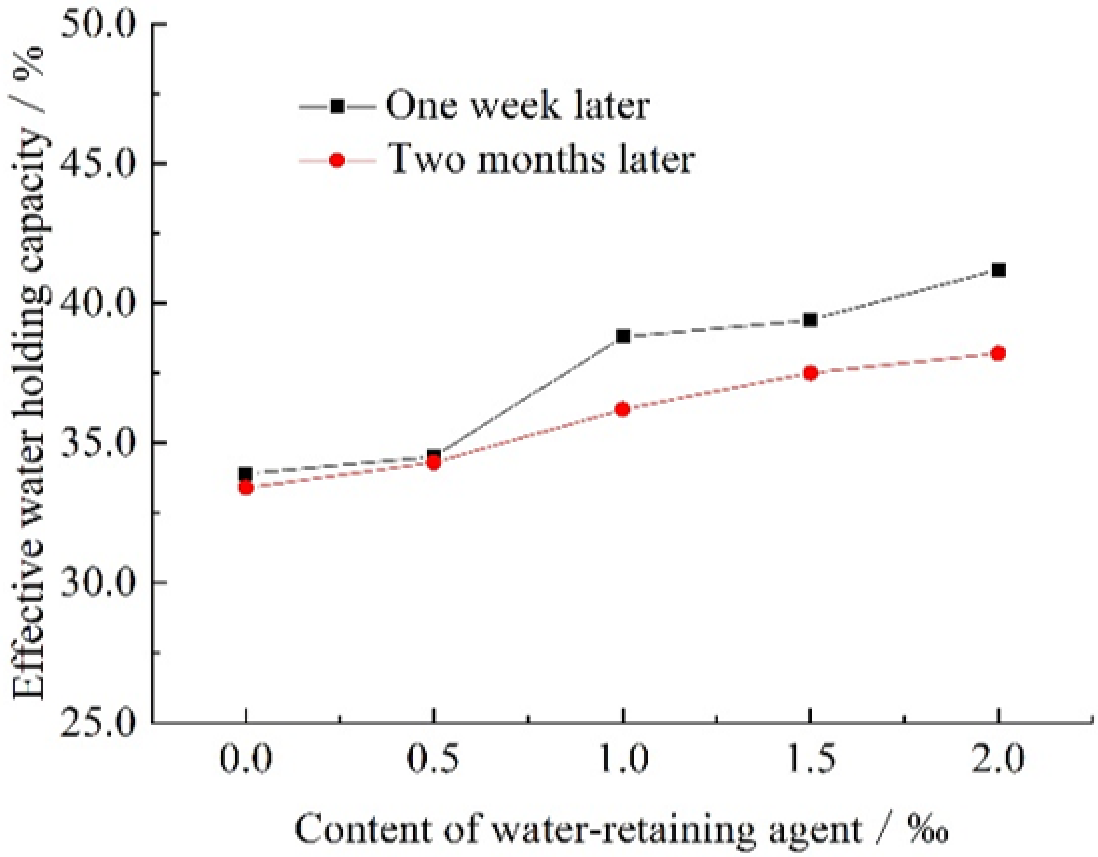

Figure 4

Relationship of effective water capacity of guest soil and absorbent agent content

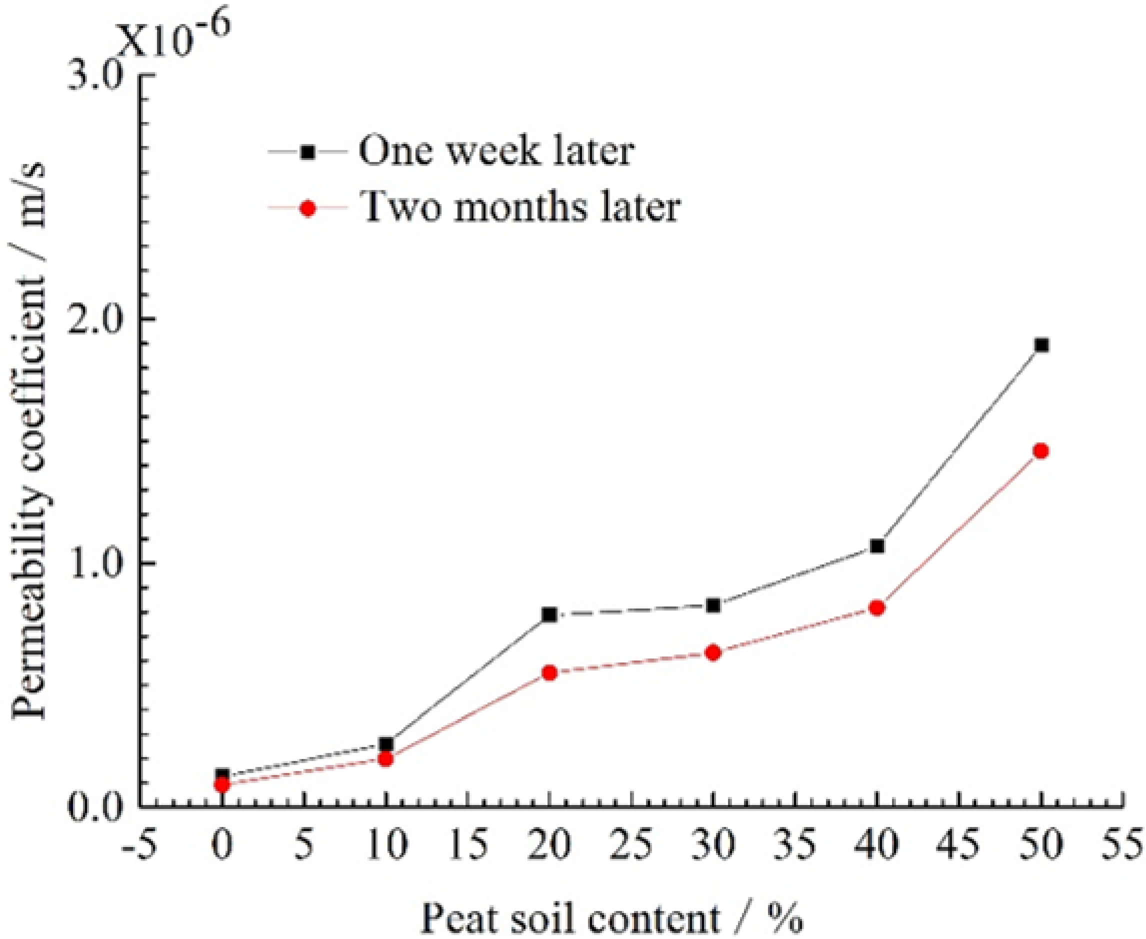

Figure 5

Relationship of permeability coefficient of guest soil and water-retaining agent

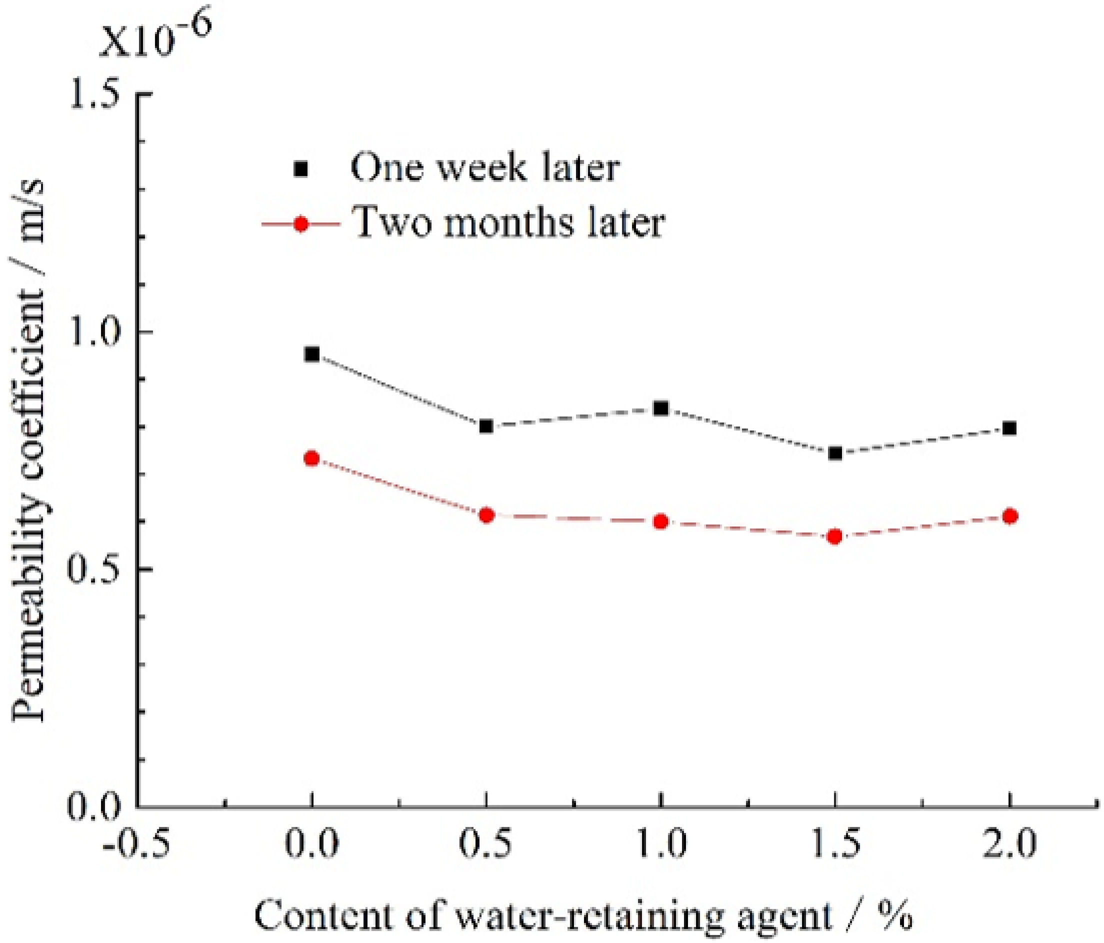

Figure 6

Relationship of permeability coefficient of guest soil and peat content

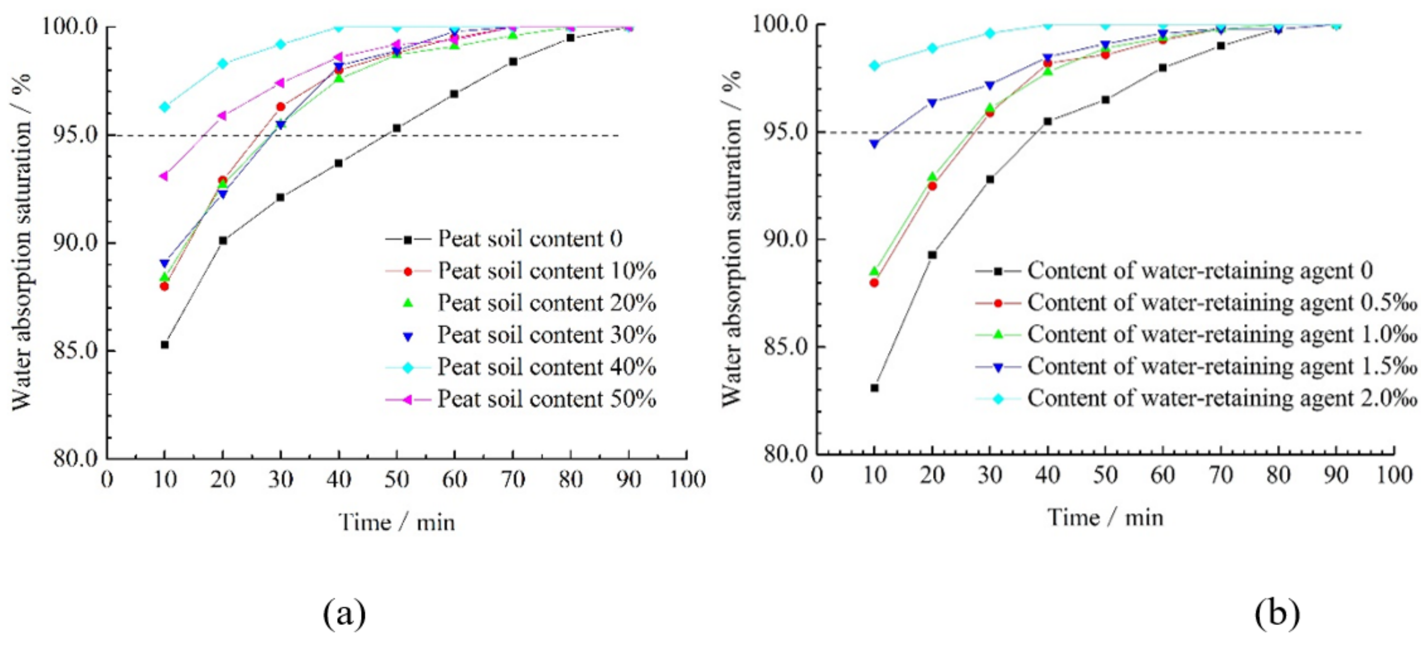

Figure 7

Relationship of water absorption saturability of guest soil and time

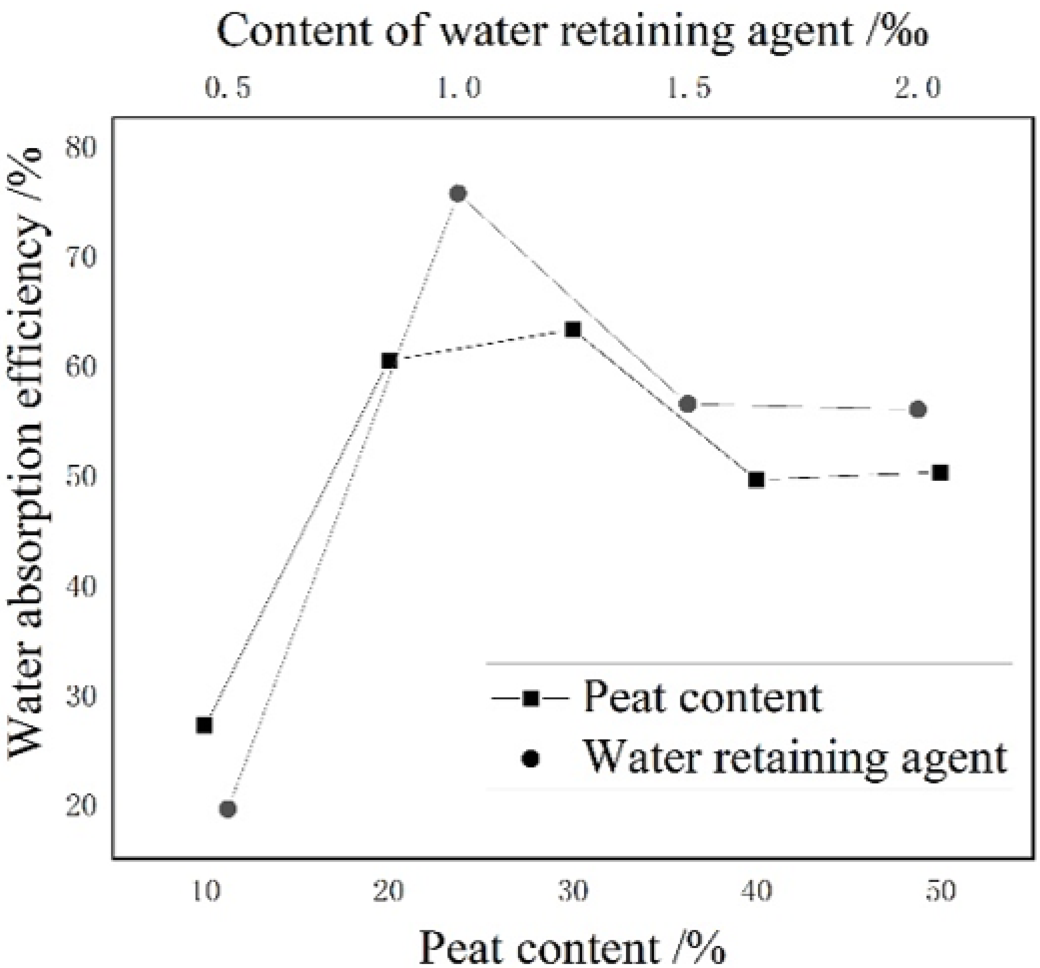

Figure 8

Relationship of efficient ratio of water absorption and improved materials content

Figure 9

Guest soil spraying test on site

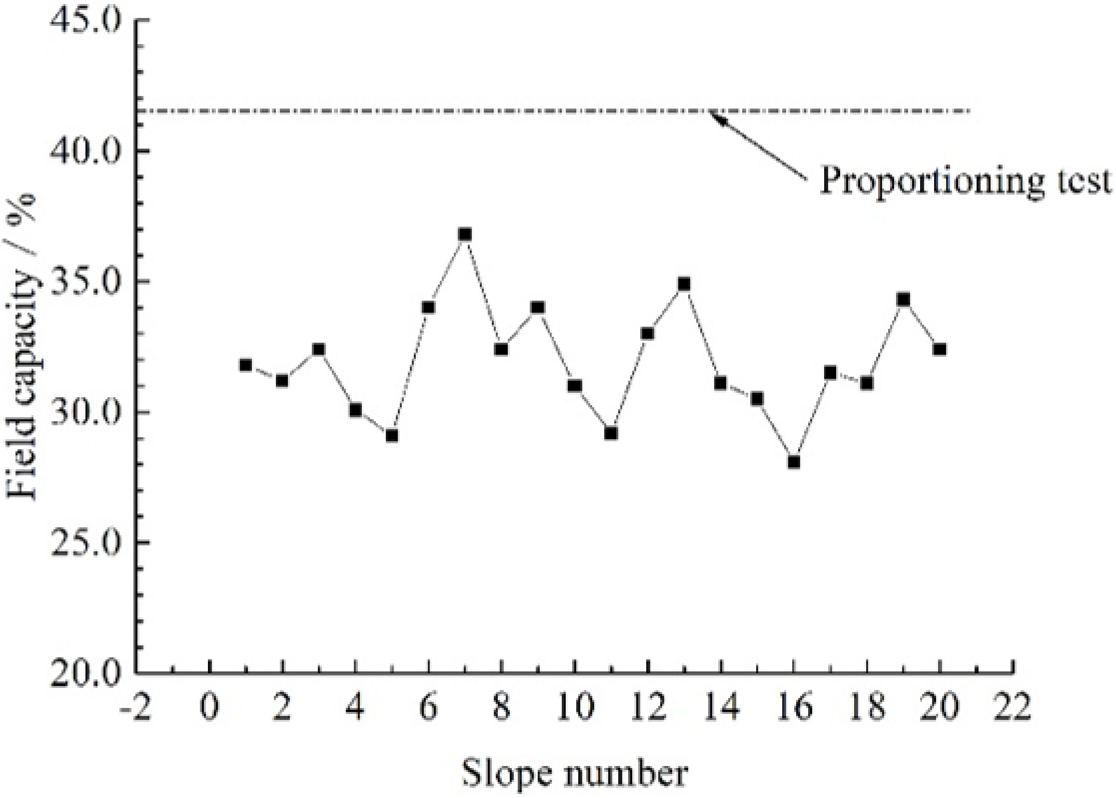

Figure 10

Field water capacity of guest soil

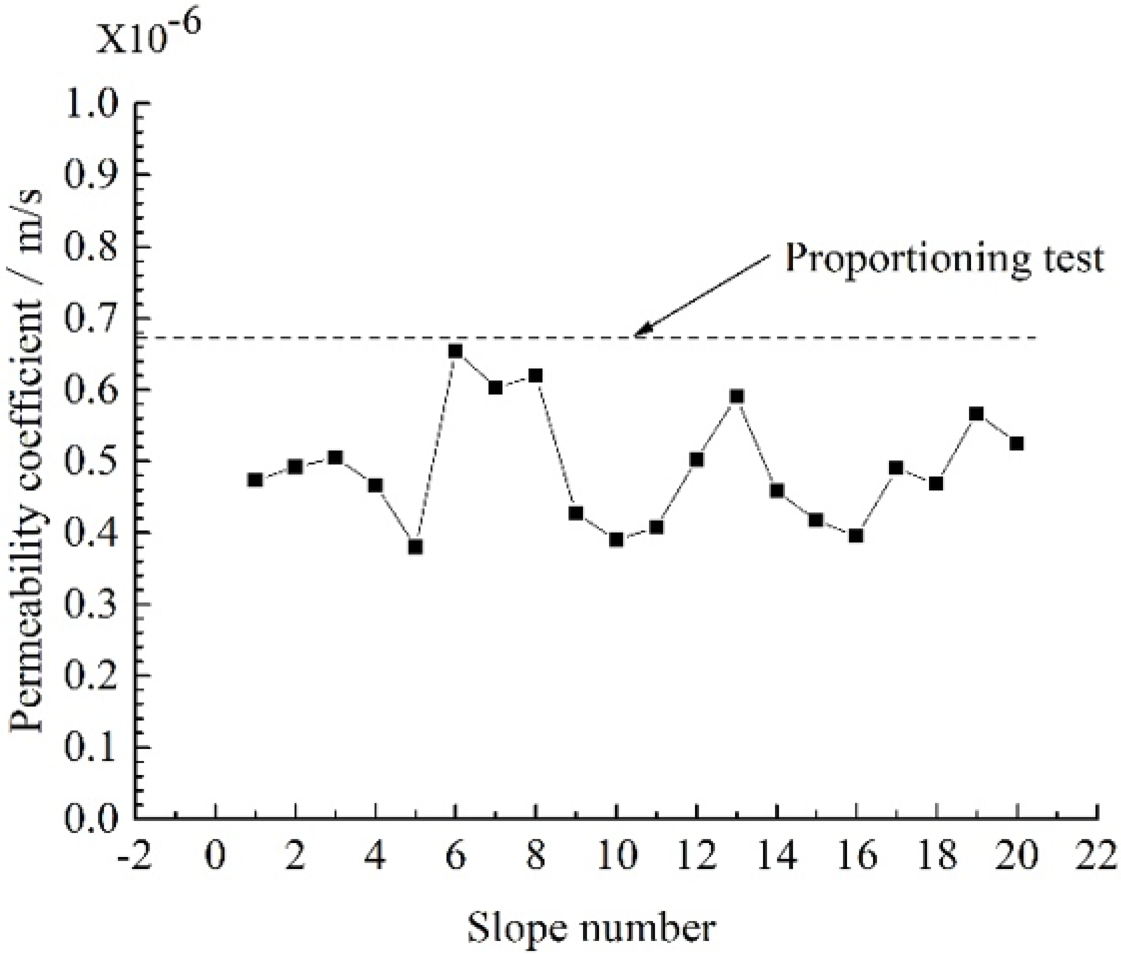

Figure 11

Permeability coefficient of guest soil

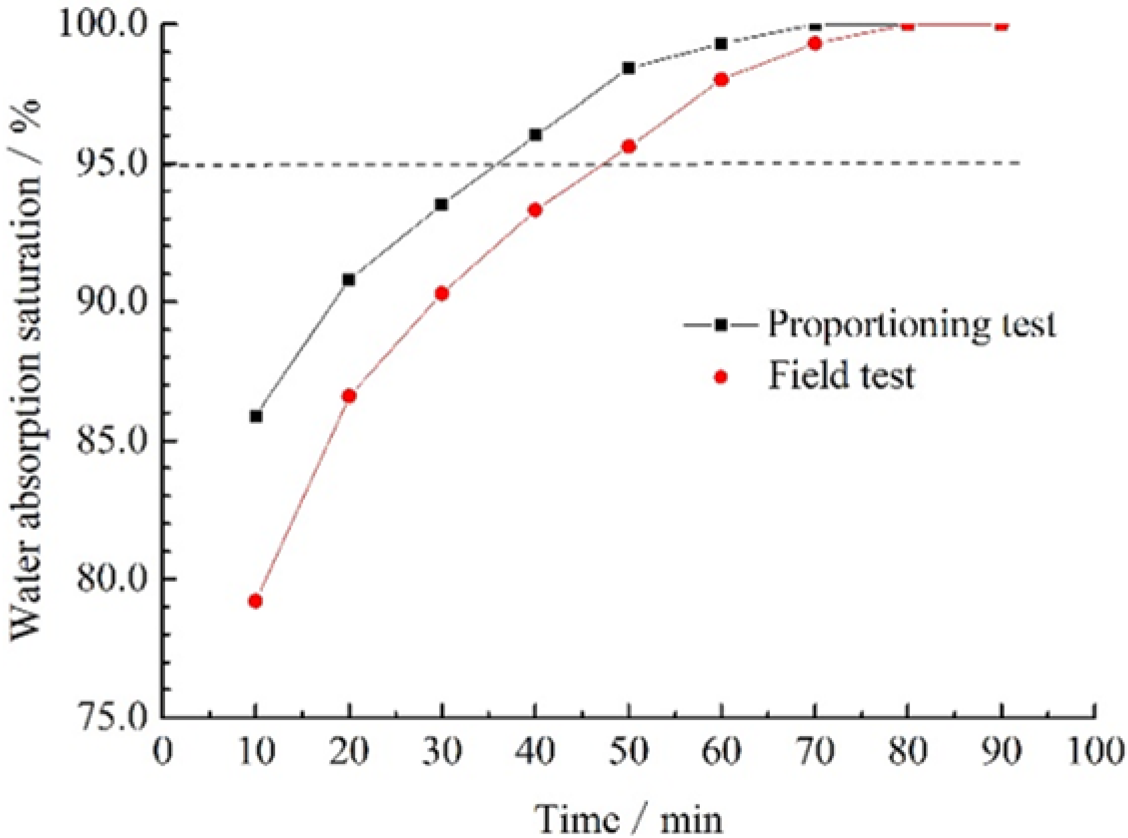

Figure 12

Relationship of water absorption saturability of guest soil and time

Figure 13

Slope plants growth status