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ABSTRACT

Karst rocky desertification (KRD) is a global environmental degradation problem caused by human activities and vegetation deterioration. Vegetation restoration in KRD is very difficult due to severe water loss, soil erosion and extensive bare bedrock. For achieving vegetation restoration on bare bedrock areas of KRD, the nutrient medium technique was developed, which is based on the special hydro-geological conditions that is seasonal rainfall is abundant in Karst region of Southwest China and limestone fissures are extremely developed and rich in fissure water. The objective of this research is to investigate the feasibility of using nutrient medium technique to achieve vegetation restoration in KRD region. Through the indoor and field experiments, some properties of the nutrient medium mixture were tested, including water retention, water absorption and nutrient retention. The results showed that the moisture content on the 75th day and water absorption rate of No.2 mixture was 19.9% and 1.67 mm/d, respectively, which could be used as optimum mix ratio for producing nutrient medium. The field results showed that the nutrient medium technique could effectively guarantee the survival of sapling at early age and sustainable growth at later age in the field, and the nutrient medium had less nutrient loss. This novel approach can retain and absorb moisture, and saplings do not need artificially supply water and fertiliser in the dry season, and the use of nutrient medium technique to achieve vegetation restoration in KRD region seems to be a feasible option.

1. Introduction

Karst rocky desertification (KRD) is utilised to characterise the processes that transform a Karst region covered by vegetation and soil into a rocky landscape almost devoid of soil and vegetation (Gao et al. 2013; Wang et al. 2004), which is one major type of desertification caused by human impacts on the vulnerable eco-geo-environment (Huang et al. 2009;
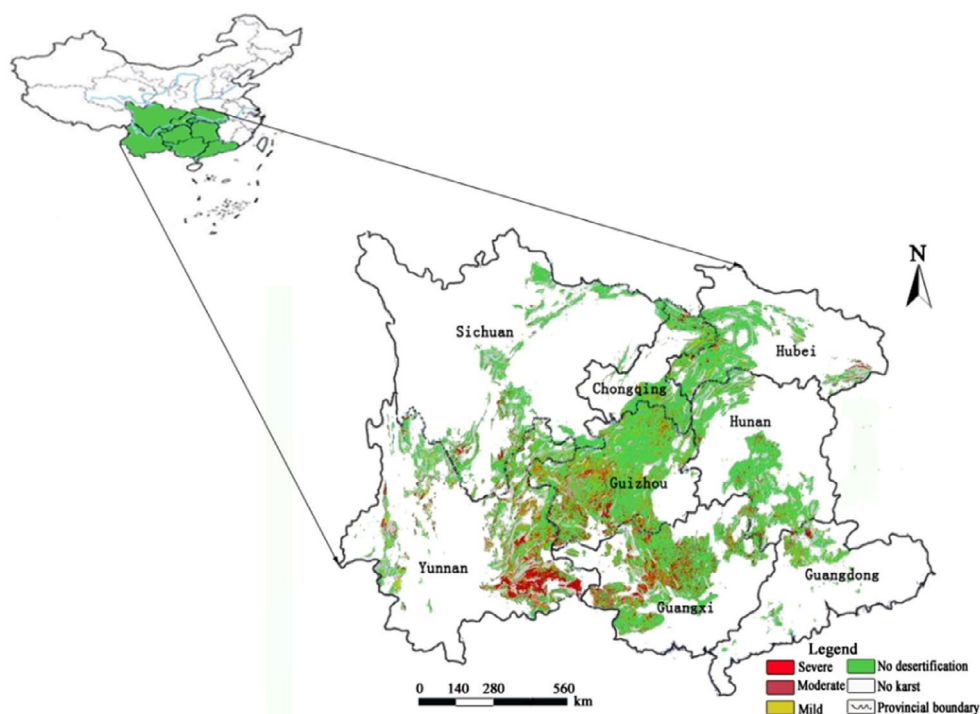
Figure 1. Distribution of Karst rocky desertification areas in Southwest China. Source: The Ministry of Natural Resources of China (http://www.mlr.gov.cn/zxgz/ddc/dzzhyj/zycg/200710/t20071019_89026.htm), and the Geological Survey of China (http://www.agrs.cn/yyly/1477.htm).

Li et al. 2009). KRD is a global phenomenon of environmental degradation that is mainly distributed in European Mediterranean basin (Mauro et al. 2012), the Dinaric Karst (Gams and Gabrovec 1999) and Southwest China (Yuan 1997). In addition, KRD landscapes are also widely found in other countries or regions of the world, such as in Belize, Guatemala, Mexico of North America, Israel of the Middle East, East and south-east of Asia, including the Ryukyu Islands of Japan and Gunung Sewu of Indonesia (Ford and Williams 2007).

Karst landscape in southwest China is one of the most archetypal landscapes developed on limestone in the world (Liu 2009). The distribution of KRD in Southwest China is shown in Figure 1. China has approximately 3.44×10^6 km^2 of Karst areas, about 36% of its total land and 15.6% of all the 2.2×10^7 km^2 Karst areas in the world (Song et al. 2017a), and the bare carbonate areas is approximately 0.51×10^6 km^2, which accounts for 14.8% of all Karst areas in China (Jiang et al. 2014). KRD region in Southwest China is one of the most concentrated Karst areas in the world, which mainly includes seven provinces (or municipalities) of Guizhou, Yunnan, Sichuan, Guangxi, Guangdong, Hunan, Hubei and Chongqing.

KRD has become a major ecological disaster in Southwest China, which has seriously affected hydrology, soil and ecology at various scales, and consequently caused a lot of geological disasters such as droughts, floods, landslides and land subsidence. According to incomplete statistics, the annual loss of arable land more than 200 km^2, and economic losses exceed tens of billions yuan each year. More importantly, the lives of 50 million people in Karst region were indirectly affected, and most of their living standards were below the poverty line (Jiang et al. 2011; Yang et al. 2014). The ecological disaster of KRD had seriously

hindered the economic growth in Southwest China (Jiang and Yuan 2003). Therefore, the control of the development of KRD has become an urgent task.

The unique Karst landscape was mainly formed by the dissolution of carbonates, including limestone and dolomite. In Karst region, soil was considered as a valuable resource due to the slow soil formation and erosion (Sarah Kimberley et al. 2012; Kallioras and Marinos 2015). In addition, the hydrological dynamic system in the KRD region was unevenly distributed in both vertical and horizontal directions due to the high development of the Karst conduit network (Song et al. 2017a). The degree of development and connectivity of the Karst conduit network depended on weathering of rocks, soil erosion and chemical dissolution in the hydrological process (Song et al. 2017b). A large amount of precipitation was rapidly flowed through the Karst conduit network after rainfall, and the surface runoff coefficient was very low (Pamela et al. 2014), and soil moisture and nutrients could easily enter underground Karst conduit network during the rainfall season. Song et al. (2017b) studied that the relationship between rainfall and loss of nitrogen in the Karst slopes by a simulated rainfall test, and reported that 90% of the nitrogen losses occurred during the rainy season and most of them penetrated into the Karst conduit network. Loss of water and nutrients were seriously hindering the restoration of vegetation in KRD region (Li et al. 2013). Therefore, the retention and storage of water, and the reduction of nutrient loss were crucial for vegetation restoration in KRD region (Janet and Peter 2012).

In recent decades, in order to reduce and control the hazards of KRD, many measures had been taken to reduce water loss and soil erosion in soddy Karst and buried Karst areas. Zhao et al. (2015) reported the use of a combination of local dominant species and introduced species for the restoration of vegetation. Xiao SZ and Xiao H (2012) reported that the mixed model of grassland construction and ecological livestock husbandry was suitable for controlling KRD in Hezhang county. Xiong et al. (2012) reported that slope lands changed to terraces were effective measures to relieve soil erosion and water loss in KRD. However, although these measures can reduce the further expansion of KRD to a certain extent, the vegetation system has not been stabilised and is still prone to degradation (Li et al. 2014; Zhang et al. 2016).

To achieve the goal of vegetation restoration in KRD region, the most basic method is to reforestation (Wang et al. 2013; Janet and Peter 2012). Previous studies on reforestation techniques for KRD regions were very scarce, especially in bare Karst areas (No soil and water, only bedrock). Yang (2010) proposed a method of planting trees on bare Karst areas that first formed a rock hole through explosion, and then planted seedlings in the rock hole. Due to the high temperature and the strong solar radiation in the dry season, and water and nutrients were easily lost to the Karst conduit network in the rainy season (Yang et al. 2013). Therefore, this simple method of planting trees did not guarantee the long-term survival of the seedlings and the blasting also easily caused other environmental damage problems.

A novel plant tree method, the nutrient medium technique was developed to achieve vegetation restoration on bare bedrock areas of KRD (Chen and Wu 2015). The nutrient medium technique includes the nutrient medium matrix, water absorption bar and anti-evaporation cover (Figure 2). The nutrient medium matrix can absorb and store the rainfall, and then release slowly, and to provide nutrients for early growth of saplings, which is an important part of nutrient medium technique. However, the optimum mix ratio, water retention, water absorption and nutrient retention of the nutrient medium matrix need to be studied. Therefore, the overall aim of this study was to investigate the water retention and nutrient
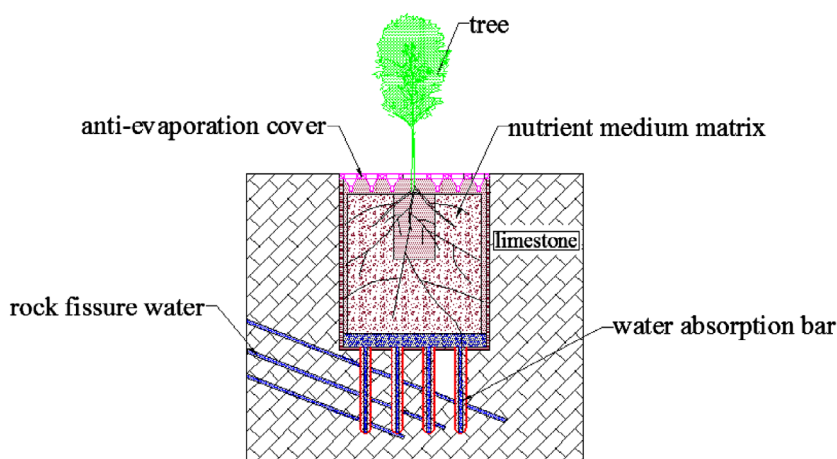
Figure 2. Structural diagram of nutrient medium technique for tree planting.

retention characteristics of nutrient medium matrix and the feasibility of using nutrient medium technique to plant trees in bare KRD region. The specific objectives were to: (1) analyse the effects of various constituent materials on water retention properties of mixtures and on seedlings growth, (2) assess the water absorption properties of four groups optimised mixtures (No.2, No.5, No.15 and No.20) and (3) conduct a field experiment to evaluate nutrient retention of No.2 mixture and growth of saplings.

2. Materials and methods

2.1. Material used

The nutrient medium matrix was a cylindrical mixture, which was shaped under a certain pressure, and a hole for tree planting was reserved in the middle of its upper surface (Figure 2). The mixtures include mushroom residue (MR), crop straw (CS), cow dung compost (CDC), loam, vermiculite, super absorbent polymers (SAP), binder and water. In this study, MR was collected from a local mushroom breeding plant, and sieved with 1-cm sieve to remove coarse particles and other solid wastes. CS and CDC had a maximum size of 1 mm, and obtained from a local farm. Before CS was fermented, they were air-dried and then crushed into a fibrous form. Loam was obtained from the topsoil of local farmland, which was air dried before crush and sieved with 1-cm sieve. SAP with a water absorption rate of 300~500 times was produced by the Zhengzhou Biaodian Chemical Co., Ltd. Vermiculite with particle size of 1~2 mm was produced by Zhejiang Guomei Horticulture Co., Ltd. Fertiliser used in this study was universal long-term organic compound fertiliser, and produced in Chongqing Garden Fertilizer Co., Ltd. The binder was polyvinyl alcohol (PVA-224) of water-soluble synthetic resin.

2.2. Experimental design

The experiment was conducted in three phases. The phase I focused on investigate the effects of MR, CS, CDC, SAP, vermiculite and binder on the water retention of mixtures. In view of seasonal drought in KRD region, water retention property was an important index

Table 1. Mix proportions of nutrient medium mixtures (volume ratio%).

Group	Mix.No.	MR	CS	CDC	Loam	SAP	Vermiculite	Fertiliser	Binder
A	1	*5*	25	20	47	0.15	2.5	0.3	0.05
	2	*10*	25	20	47	0.15	2.5	0.3	0.05
	3	*15*	25	20	47	0.15	2.5	0.3	0.05
	4	*20*	25	20	47	0.15	2.5	0.3	0.05
B	5	10	*5*	35	47	0.15	2.5	0.3	0.05
	6	10	*10*	35	47	0.15	2.5	0.3	0.05
	7	10	*15*	35	47	0.15	2.5	0.3	0.05
	8	10	*25*	35	47	0.15	2.5	0.3	0.05
C	9	10	20	*10*	57	0.15	2.5	0.3	0.05
	10	10	20	*15*	57	0.15	2.5	0.3	0.05
	11	10	20	*20*	57	0.15	2.5	0.3	0.05
	12	10	20	*25*	57	0.15	2.5	0.3	0.05
D	13	5	15	20	57	*0.05*	2.6	0.3	0.05
	14	5	15	20	57	*0.1*	2.6	0.3	0.05
	15	5	15	20	57	*0.2*	2.6	0.3	0.05
E	16	5	15	20	57	0.15	*1.5*	0.5	0.05
	17	5	15	20	57	0.15	*2*	0.5	0.05
	18	5	15	20	57	0.15	*3*	0.5	0.05
F	19	5	15	20	57	0.2	2.2	0.5	*0.1*
	20	5	15	20	57	0.2	2.2	0.5	*0.15*
	21	5	15	20	57	0.2	2.2	0.5	*0.2*

Note: MR(mushroom residue), CS (crop straw), CDC (cow dung compost) and SAP (super absorbent polymers). The bold italic values in Table 1 indicate the differences in the parameters of the mixtures in each group.

for predicting the drought resistant performance of nutrient medium matrix under severe sustained drought condition. A total of 21 batches of mixtures were prepared, and they were grouped into A, B, C, D, E and F, respectively, and corresponding to the difference in the content of MR, CS, CDC, SAP, vermiculite and binder, respectively. For example, No.1–No.4 mixtures were grouped into group A, which investigated the effect of different MR content on the performance of mixtures, and other blended materials content in group A was the same except for MR content. Mix proportions of nutrient medium mixtures were showed in Table 1.

To directly observe the growth of seedlings, seeds of Amorpha fruticosa were used in this study due to its fast growth rate, and obtained from the local nursery garden. Before seeds were sown, and they were soaked in warm water at 60~70 °C for accelerating germination. A total of 20 seeds were sown into each flowerpot. The water retention test was conducted from 5 July to 25 September due to the highest ambient temperature in summer and the seedlings were not watered and fertilised in this test. After seeds were sown in different mixtures, they were not watered and fertilised and the status of plant growth and the moisture content of mixtures were continuously observed and recorded each 15 days, and the experiment was not stopped until plant died or moisture content less than 20%. Due to no watering in this experiment, all plants grew well on the 30th day and most of plants grew slowly or died after the 30th day, thereby the plant height on the 30th day was recorded as the seedling height.

The phase II focused on the water absorption characteristics of mixtures in the short-term and long-term water conditions. In view of seasonal precipitation in KRD region, water absorption characteristics implied the capacity of the nutrient medium matrix to absorb rainwater quickly, which was helpful to improve the water use efficiency and promote sapling growth. According to the results of water retention test, four groups optimised mix (No.2, No.5, No.15 and No.20) were selected for water absorption test. Each mixture was prepared in duplicate, and then they were put into flowerpots. After saplings survived, flowerpots

Table 2. The feature of rock holes used for tree planting.

No.	Shape of hole	Length (cm)	Width(cm)	Depth(cm)	Number of bottom holes
1	Rectangle	25	22	30	5
2	Circle	23	23	32	5
3	Circle	25	25	30	4
4	Rectangle	25	22	30	7
5	Circle	23	23	30	6
6	Circle	27	27	31	4
7	Circle	26	26	27	5
8	Rectangle	28	22	25	5

Table 3. The basic parameters of saplings used in field experiment.

| No.	Tree species	Height(cm)	Diameter(cm)
1	Ficus virens	46.5	0.8
2	Platycladus orientalis	45.8	0.3
3	Panax stipuleanatus	91.1	0.9
4	Platycladus orientalis	25.0	1.3
5	Ficus virens	56.0	0.3
6	Ficus deltoidea	112.0	0.5
7	Panax stipuleanatus	92.0	0.8
8	Ficus deltoidea	70.7	0.5

with saplings were put in a pot with the initial water level of 20 mm (a total of four groups) and 40 mm (a total of four groups). Due to the water absorption and capillary action of mixtures, water could be transported up to roots through four reserved circular holes with a diameter of 1 cm at the bottom of flowerpots. Osmanthus fragrans saplings were used in this test, and obtained from the local nursery garden. The initial saplings height was 45~50 cm and the basal diameter was 0.3 ~0.5 cm. Mixtures moisture content and the saplings were continuous observed every five days, and the experiment was not stopped until water in the pot was totally absorbed or the moisture content was more than 90%.

In phase III, the field experiment was carried out to evaluate nutrient retention and growth of saplings in the field. Due to No.2 mixture had good water retention and absorption characteristics, which was used in field experiment. A total of eight rock holes used for tree planting were excavated in the field. The feature of rock holes used for tree planting was presented in Table 2. A total of four kinds of tree species, two saplings of each tree species were used, and they were obtained from the local farms. The basic parameters of saplings were presented in Table 3. In addition, in order to investigate the nutrient retention of No.2 mixture, the nutrients of No. 2 mixture were determined according to the method prescribed in the soil agrochemical analysis (Bao 2013), including organic matter, available nitrogen, available phosphorus and available potassium. After the saplings were planted in the field, the mixture at 10–15 cm was obtained, and after smashed and sieved after air drying, the nutrient content of No.2 mixture was determined every 30 days.

2.3. Experimental procedure and test methods

The preparation of mixtures can be listed as follows: firstly, weighed the materials needed for each mixture according to the mix design (Table 1), and blended in a mixer for 2 min. Then, 1500-ml water was added to the mixtures and mixed for another 3 min. Secondly, the
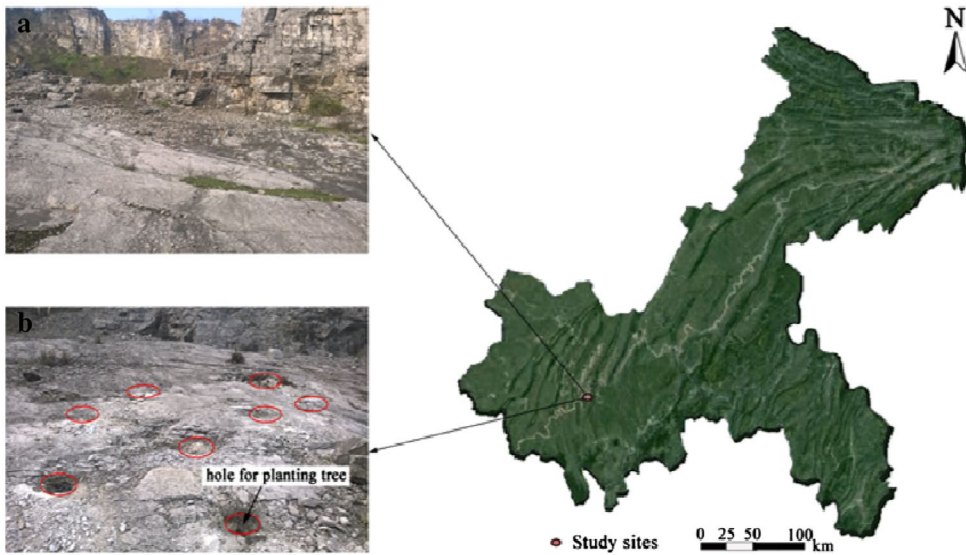
Figure 3. Location of study site at Nanshan, Chongqing. (a) large areas of bare rock, (b) distribution of rock holes.

mixtures were poured in the corresponding numbered flowerpots (No.1~No.21) with a bottom diameter of 15.7 cm, a height of 17.6 cm and a top diameter of 23 cm. Lastly, a total of 20 seeds of Amorpha fruticosa were sown into each flowerpots until the soil moisture content decreased to 60%~70%. The moisture content of the mixtures was determined biweekly using the SIN-TH8 soil moisture analyzer. The height of Amorpha fruticosa was continuously observed after germination. The average daily temperature was 33.5 °C during the observed period.

Water absorption test was carried out at the Laboratory of Geotechnical Engineering Institute of Chongqing Jiaotong University, and began on 1 December 2015. Firstly, each mixture (No.2, No.5, No.15 and No.20) was prepared and was put into flowerpots. Secondly, saplings were transplanted in the flowerpots, and then flowerpots with saplings were moved to the balcony. Lastly, after the saplings survived, all flowerpots were put into a pot with the initial water level of 20 and 40 mm, respectively.

The field experiment was conducted in Nanshan, Chongqing city (106.33 E, 29.35 N). This site was located at the limestone region. A large areas of bedrock was exposed to the surface of field test site, and the fissures were well-developed in limestone rock mass as well as the rock surface was barren (Figure 3). Chongqing was located in Southwest China, and mean annual temperature was 16~18 °C, which was subtropical humid monsoon climate featuring abundant precipitation, plenty of sunshine, no snow and less frost. Chongqing was extremely hot in summer, which was the nationally famous high-temperature zone. The maximum daily temperature was above 35 °C from July to August and the maximum limit temperature up to 43.8 °C. Average annual precipitation was rich and ranges between 1000 and 1350 mm. Precipitation between May and September accounted for about 70% of the total annual precipitation.

The process of excavated rock holes was showed in Figure 4. Firstly, cleaned up the rubble and garbage of the rock surface, and then eight rock holes used for tree planting were
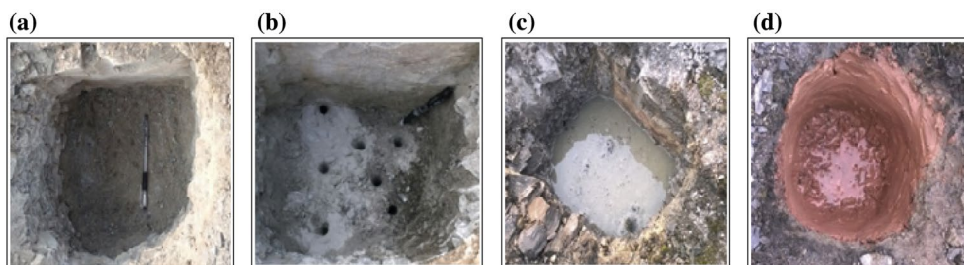
Figure 4. The process of excavated rock hole. (a) excavated rock hole, (b) bottom holes used for water absorption bar, (c) moisten the rock hole with water, (d) smeared with clay slurry on the wall of rock hole.

excavated in test site by artificial cutting and a blower gun. Subsequently, 4~7 bottom holes with a diameter of 2 cm and a depth of 50~80 cm for installing water absorption bar were drilled at the bottom of excavated rock holes. Then, water was poured into rock holes to moist the rock holes. The slurry, mixed by clay and water, coated on the wall of rock holes to reduce the water leakage. The procedures of install the nutrient medium matrix can be listed as follows: (1) The pre-made water absorption bar was inserted into the bottom hole; (2) The nutrient medium matrix was placed in rock hole; (3) The sapling was planted in the reserved hole of nutrient medium matrix, and the space between nutrient medium matrix and rock hole was filled with incompact nutrient medium; (4) The anti-evaporation cover was placed on the surface of the nutrient medium matrix. After planting, saplings were watered, and they were not watered and fertilised during the test period. Saplings were transplanted on 1 February 2016, and continuously observed since 20 April 2016.

3. Results

3.1. Seedlings height

Effects of different component content on seedlings height on the 30th day are shown in Figure 5. The results showed that the seedlings height increased firstly and then decreased with increasing in MR content. In addition, the MR content of 10, 15 and 20% had a significant effect on seedlings height ($p < 0.05$). With the increase of CS content, seedlings height gradually decreased due to CS increased the porosity of the mixture, and there was a significant difference in seedlings height when adding more than 10% CS to the mixture. The addition of CDC in the mixture exceeded 10% had a significant effect on seedlings height, while the increased in seedlings height after adding more than 15% CDC was not significant. The more SAP the higher seedlings height. However, an increased in SAP from 0.05% to 0.1%, seedlings height increased by 2.8 cm, the SAP varied from 0.1 to 0.2%, seedlings height only increased by 1.2 cm. This phenomenon showed that SAP exceeded a certain value, the effect of SAP on seedlings height would be slowed down. When vermiculite and binder content were 2.0 and 0.15%, respectively, the height of seedlings reached the highest and they were 5.8 and 9 cm, respectively.
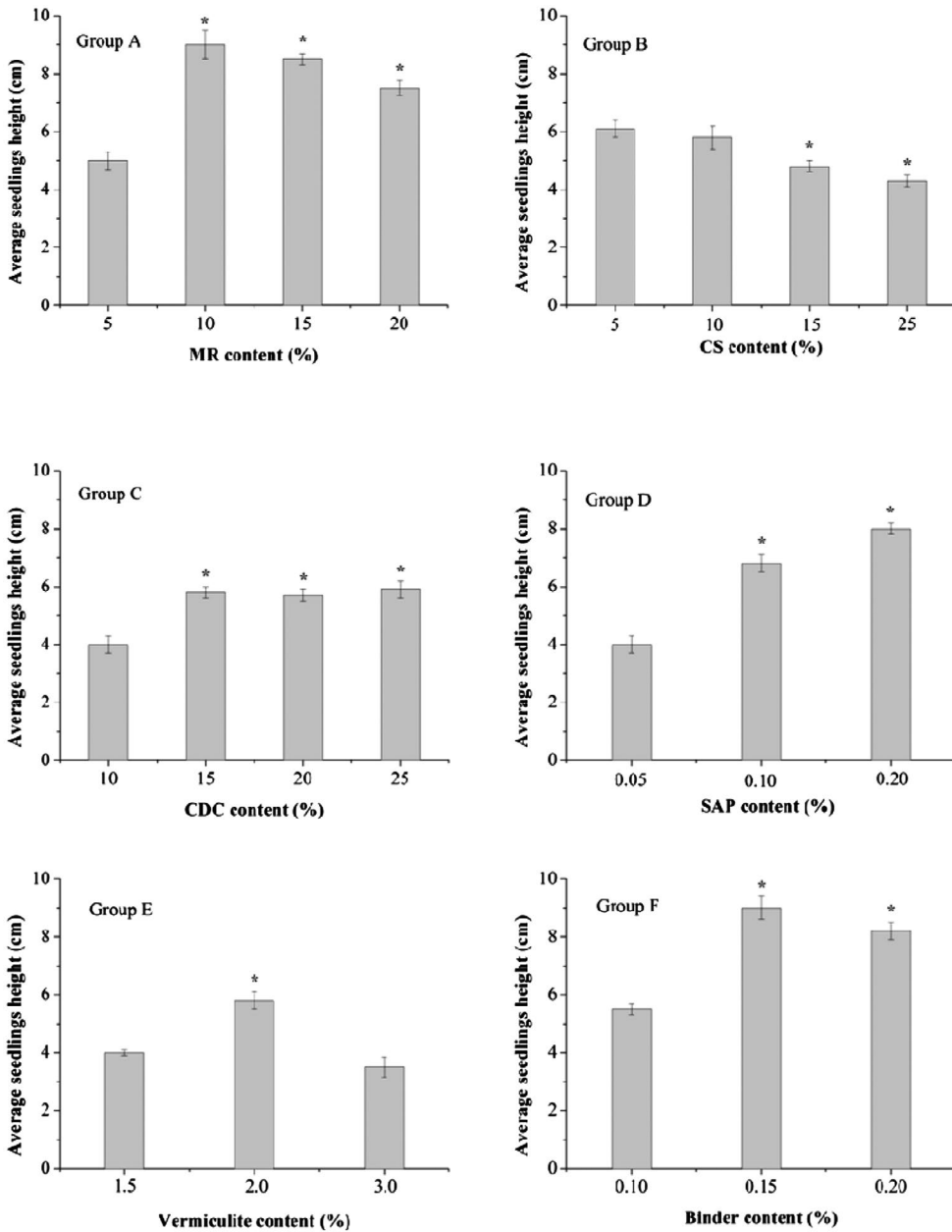
Figure 5. Effects of different component content on seedlings height (on 30th day). Note: * indicates that the factor is a significant correlation ($P = 0.05$).

3.2. Water retention

Relationship between the moisture content of mixtures and the time are shown in Figure 6. The results showed that the moisture content gradually decreased with the increase of time, and the rate of decrease was fastest from the 15th day to the 30th day due to the high temperature and no watering. The results showed that there was a significant difference ($p < 0.05$)
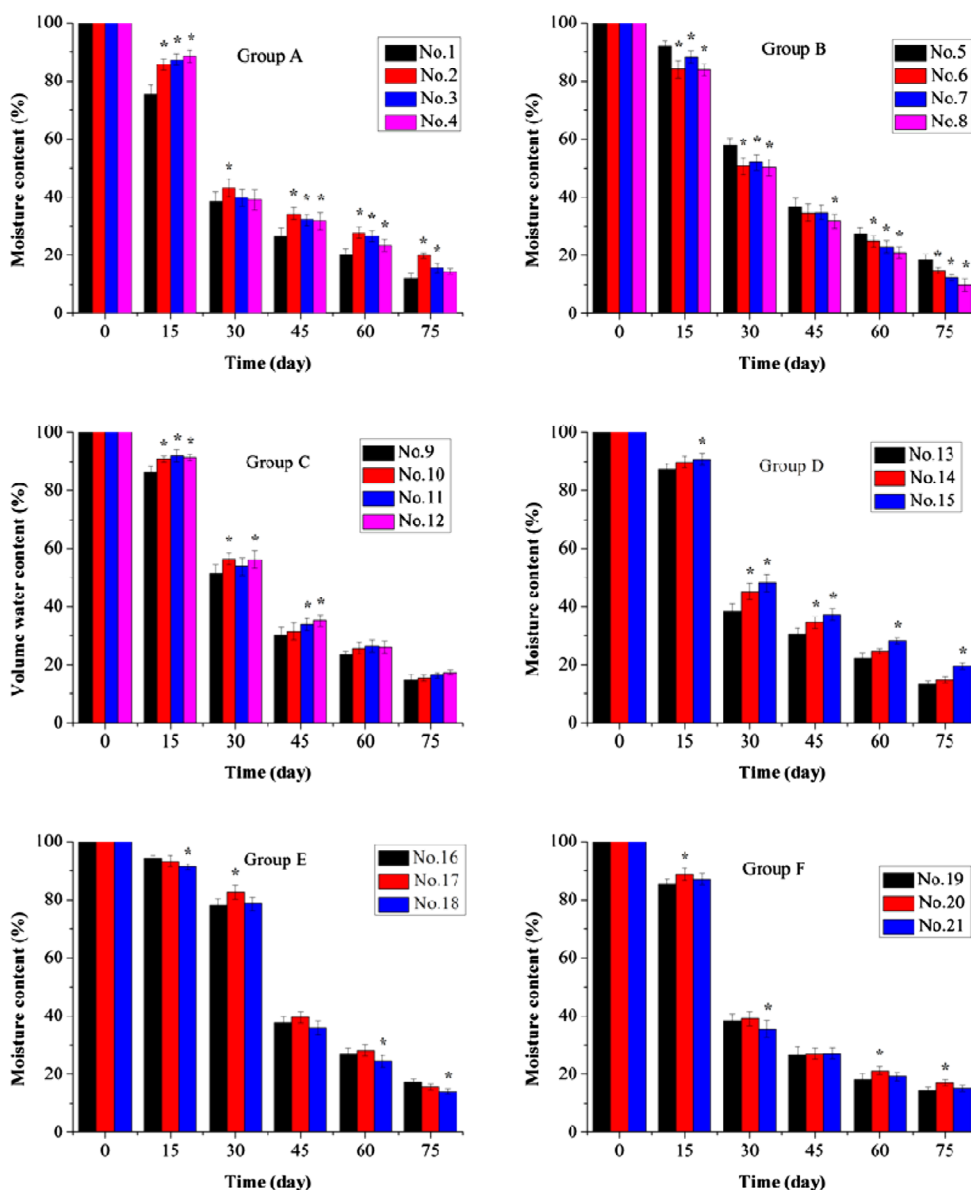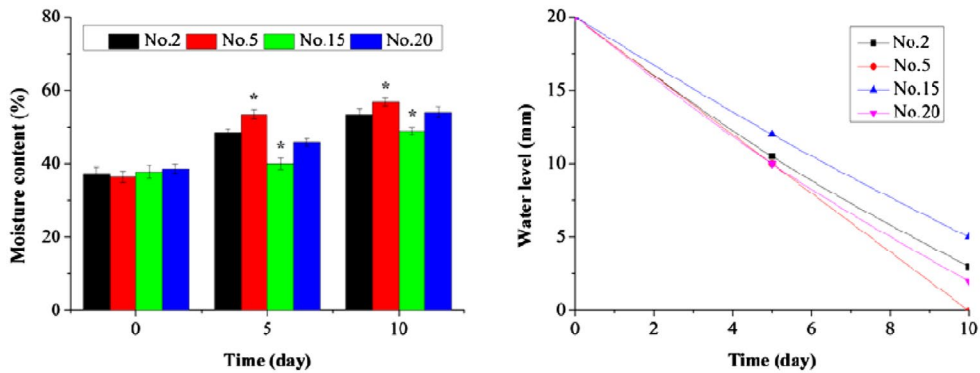
Figure 6. Relationship between the moisture content and the time. Note: * indicates that the factor is a significant correlation ($P = 0.05$).

in water retention between No. 1 and No. 2 in group A. The addition of CS content significantly reduced the moisture content, No. 8 had the worst moisture content in Group B at all days. This was due to the CS fibres increased the porosity of the mixture and the micro-passage of moisture evaporation. There was no significant difference in the moisture content in the Group C and Group E at all days, and indicating that CDC and vermiculite had little effect on the water retention of mixtures. The effect of SAP on water retention of the mixture

Figure 7. Comparison of plant growth in No. 2 and No. 13 mixtures in water retention test.
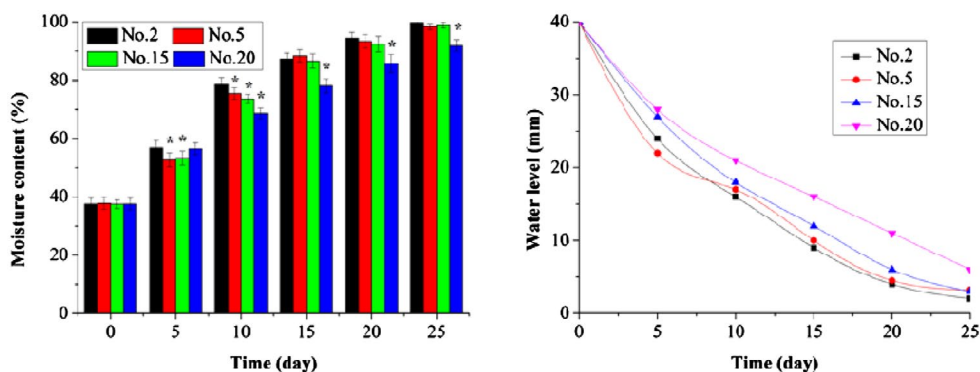

Figure 8. Relationship between moisture content and water level in the pot versus time (2 cm water depth). Note: * indicates that the factor is a significant correlation ($P = 0.05$).

was significant, and No. 15 had the highest moisture content in Group D. No. 20 in Group F had better water retention when the binder content was 0.15%.

The results showed that No.2, No.5, No.15 and No.20 mixtures had better water retention, compared to other mixtures, and the moisture content of No.2, No.5, No.15 and No.20 mixtures on the 75th day were 19.9, 18.5, 19.6 and 17.1%, respectively. Comparison of plant growth in No. 2 and No. 13 mixtures are shown in Figure 7. Due to No.2 mixture had good water retention, the plants in the No. 2 mixture grew best on the 30th day, and the growth rate slowed after the 30th day, while the plants in the No. 13 mixture began to wither after the 30th day due to no watering.

3.3. *Water absorption*

Relationship between moisture content and water level in the pot versus time (2 cm water depth) are shown in Figure 8. The results showed that there is a significant difference between the water absorption of No. 5 and No. 15 and the water absorption of No. 2, respectively,

Figure 9. Relationship between moisture content and water level in the pot versus time (4 cm water depth). Note: * indicates that the factor is a significant correlation ($P = 0.05$).
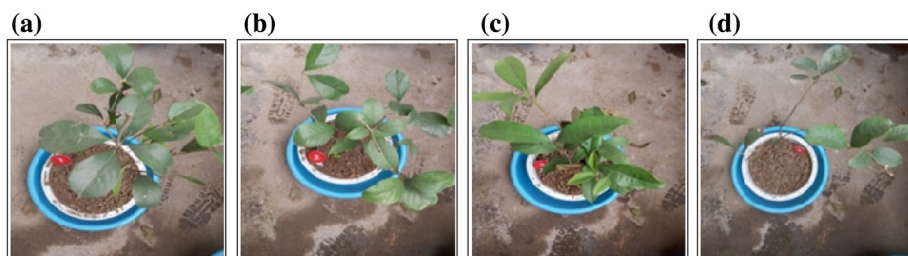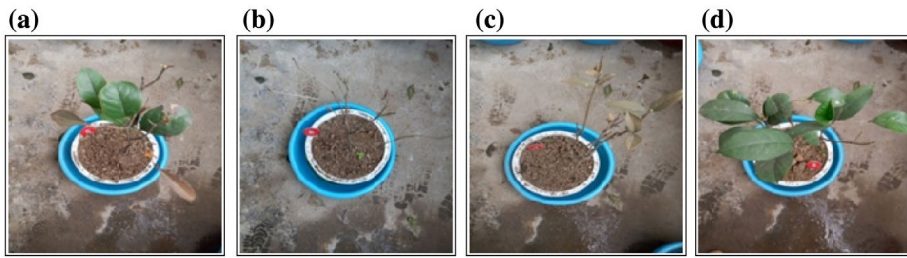

Figure 10. Growth of saplings at 2-cm water depth (on 10th day). (a) sapling 1# (No.2), (b) sapling 2# (No.5), (c) sapling 3# (No.15), (d) sapling 4# (No.20).

and the water absorption of No. 5 was the best, and that of No. 15 was the worst. The water absorption rate of No.2, No.5, No.15 and No.20 mixtures were 1.67, 2, 1.43 and 1.54 mm/d, respectively.

Relationship between moisture content and water level in the pot versus time (4 cm water depth) are shown in Figure 9. The results showed that the water absorption of No. 2 mixture was better than that of other mixtures under long-term water absorption conditions. In addition, the rate of water absorption of mixture in 4-cm water depth condition was lower than the rate of water absorption in 2-cm depth condition. Water absorption rate of No.2, No.5, No.15 and No.20 mixtures were 1.52, 1.49, 1.44 and 1.36 mm/d, respectively.

3.4. Growth of saplings in water absorption test

The growth of saplings at 2-cm water depth on the 10th day is shown in Figure 10. The results showed that all saplings grew well and new buds arose in sapling 1#, 2# and 4#, and the length of new buds was 2~3 mm, while there were no new buds in saplings 3#, and some yellow leaves began to appear. The growth of saplings at 4-cm water depth on the 25th day is shown in Figure 11. The growth of saplings showed significant differences, the No.2 mixture had no significant effect on the sapling 5# and sapling 5# only had some yellow leaves, and new green shoots with a length of 2~3 mm arose. No.5 and No.15 mixtures had a significant

Figure 11. Growth of saplings at 4-cm water depth (on 25th day). (a) sapling 5# (No.2), (b) sapling 6# (No.5), (c) sapling 7# (No.15), (d) sapling 8# (No.20).
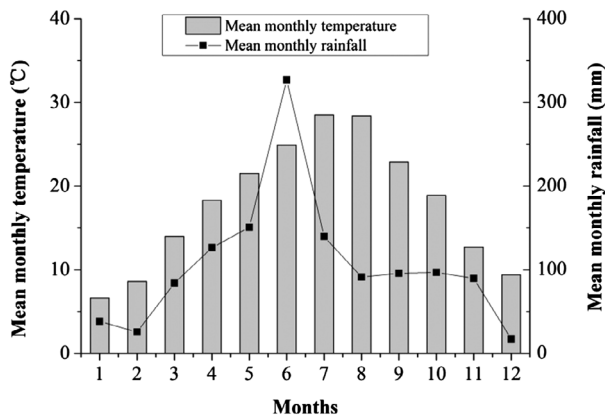
Figure 12. Monthly average temperature and rainfall in Chongqing in 2016.

effect on saplings 6# and 7# due to the saplings roots were soaked in water for a long time and gas permeability of mixtures became worse. The sapling 6# and 7# began to wither and eventually died. The sapling 8# grew well due to the slow water absorption rate of No.20 mixture.

According to the test results of water retention, water absorption and growth of saplings, it can be concluded that the water retention and water absorption of the No. 2 mixture were good, compared to the other mixtures. Therefore, No.2 mixture could be used as optimum mix ratio of nutrient medium matrix.

3.5. Growth of saplings in the field test

Chongqing city and adjacent areas suffered severe drought in summer in 2016. Monthly average temperature and rainfall in Chongqing in 2016 are shown in Figure 12. The average monthly rainfall in July and August was less than 150 mm, while the average temperature was higher than 28 °C. The results of continuous observation of sapling 1# and 6# are shown in Figures 13 and 14, respectively. The results showed that the nutrient medium technique can automatically collect and utilise rainwater or fissure water, and the saplings can survive and grow well in the field without artificially supply water, such as green shoots sprout from the sapling 1# and the length of shoots was 2.3, 14 and 15.3 cm, respectively, on 5 May, 23

Figure 13. Continuous observation of sapling 1#.

Figure 14. Continuous observation of sapling 6#.

June and 16 September. However, it should be noted that some of the new shoots of saplings were eaten by the goats, which warned us that in the early stages of vegetation restoration, livestock such as goats should be prohibited from entering the vegetation restoration areas to ensure the early survival of the saplings in KRD region.

3.6. Nutrient retention in field test

Relationship between nutrient content and time was shown in Figure 15. The results showed that although the nutrients in the nutrient medium decreased with increasing days, nutrients were not completely lost and still maintained at a high level. Compared to the nutrient content on the 30th day, the organic matter, available nitrogen, available phosphorus and available potassium of nutrient medium on the 270th day were reduced by 33.7, 37.6, 42.1
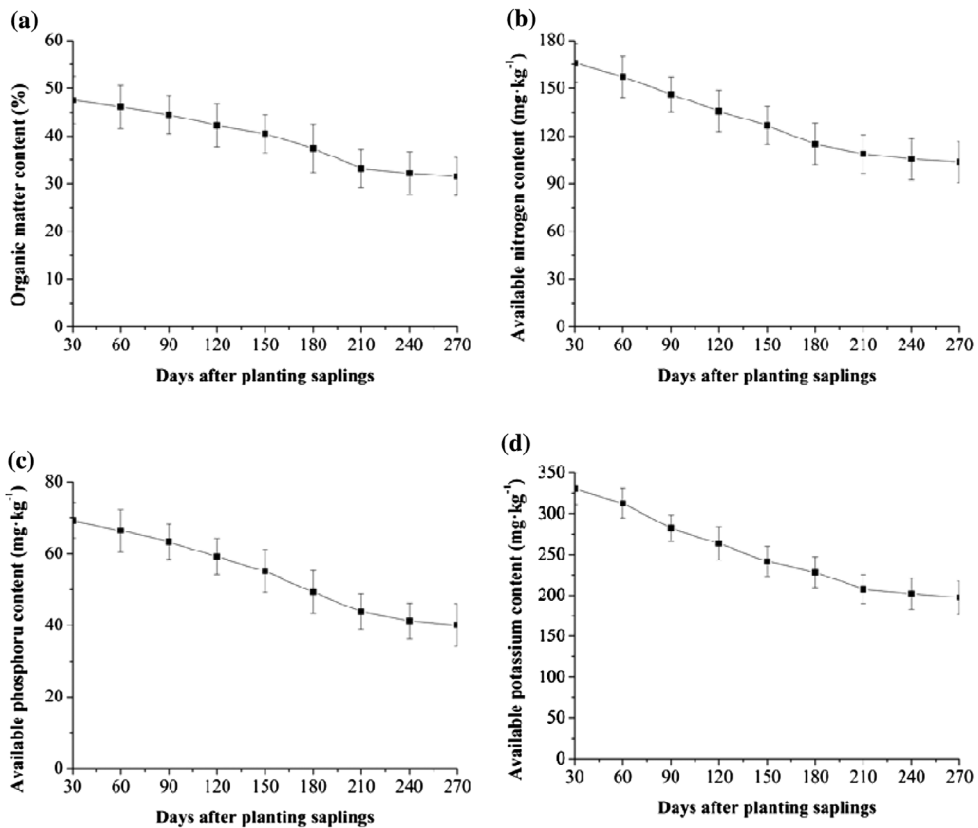
Figure 15. Relationship between nutrient content and time (a) Organic matter, (b) available nitrogen, (c) available phosphorus and (d) available potassium.

and 40.2%, respectively. In addition, the rate of nutrient loss was fast in the first 210 days, and the rate of decrease in the later stages was slowed down.

Generally, the more precipitation the faster the rate of nutrient loss, thereby the reduction in nutrients may contribute to increased precipitation in the planting area from February to September, and precipitation in subsequent monthly was decreased (Figure 12). However, with the rot of plant leaves and other organic matter in the future, and the nutrient medium can absorb Karst water containing nutrient and mineral elements, the nutrients in the nutrient medium will eventually be maintained at a suitable level, and the nutrients needed for early survival of saplings can be guaranteed by the nutrient medium.

4. Discussion

It is very difficult to carry out vegetation restoration in bare KRD areas due to the soil is barren and low water storage capacity. KRD region of southwest China is located in a subtropical climate zone, which is warm and humid in summer, and cold in winter. Water resources are abundant in Southwest China with an annual average precipitation of 1000~2000 mm and rainfall is mainly concentrated in April–September (Shen et al. 2000). However, water can transmit between adjacent epikarst through connected fissures under gravity or pore water

Figure 16. A tree grows on the exposed rock by absorbing fissure water to growth.

pressure due to the high permeability of carbonate rocks, which can easily lead to seasonal drought (Liu 2009). Nevertheless, roots of some tree species can absorb Karst fissure water by extending roots into joint fractures of the carbonatite, this unique landscape can be found in KRD region (Figure 16), especially individual tree grow on exposed rock is more likely to extract deep water sources in the late dry season (Zwieniecki and Newton 1995; Liu et al. 2012). Therefore, it is possible to recover vegetation in bare Karst areas by collecting and utilising Karst fissure water.

The nutrient medium technique is developed based on the regional hydro-geological conditions where precipitation is abundant and the development of limestone fissures in Southwest China, and the roots of the tree can extend from the rock surface to the connected limestone fissures to absorb water and minerals dissolved in the water. The nutrient medium technique includes the nutrient medium matrix, water absorption bar and anti-evaporation cover. The nutrient medium matrix provides necessary moisture and nutrients for the survival of tree saplings at early age. Water absorption bar is made of super absorbent material, which can absorb and transport moisture quickly. Due to the porous, fissured and soluble nature of the limestone (Song et al. 2017a), Karst fissure water and dissolved mineral elements in water can be continuously transported to the roots of tree by water absorbent bar. Anti-evaporation cover can reduce moisture evaporation in the dry season and reduce erosion of slope runoff in the rainy season.

Due to the KRD region in Southwest China has a steady precipitation every year, nutrient medium matrix can collect rainwater during the precipitation period and then slowly release moisture to ensure the survival and growth of saplings under severe drought condition. In addition, the bottom holes for water absorption bar is a good artificial channel for the saplings roots to extend into connected limestone fissures and to continuous absorb fissure

water. Therefore, as long as the regional groundwater resource in KRD is stable, vegetation restoration in bare KRD areas can be achieved using nutrient medium technique.

Compared to the traditional tree planting methods, the advantages of nutrient medium technique are that:

- The nutrient medium matrix, water absorption bar and anti-evaporation cover are pre-fabricated and it is an effective method to reduce the difficulty of planting trees in the field;
- The water absorbent bar can absorb fissure water from the cracks in the carbonatite or groundwater from the Karst conduit network and the saplings do not require artificial irrigation after being transplanted;
- The raw material of the nutrient medium matrix is mainly agricultural waste, extensive source and low cost are conducive to widespread application and production.

The retention and transport of nutrients directly affect the results of vegetation restoration. Generally, the loss of nutrients from seepage flow is greater than that of surface runoff (Pionke et al. 2000; An et al. 2013). Song et al. (2017b) reported that 90% of nitrogen loss occurred in subsurface in the Karst region of China. In the nutrient medium technique, due to the wall of the rock hole are smeared with clay slurry to prevent water from seepage along the fracture (Figure 4(d)) and its bottom hole is inserted into the water absorption bar, and the water absorption bar can expand under water condition and tightly adhere to the wall of bottom hole to reduce water seepage through the bottom hole. Therefore, the loss of nutrients in the nutrient medium is dominated by surface runoff, which is only a small part of the total nutrient loss. In addition, Karst water contains some residual nutrients due to the use of fertilisers, such as N (Zhang et al. 2014), and mineral elements produced by the dissolution of carbonate rocks, which can be absorbed by the nutrient medium and water absorption bar to increase the fertility of the matrix, and finally moves to root system of plants by diffusion can be absorbed by the roots (F. Somma et al. 1998).
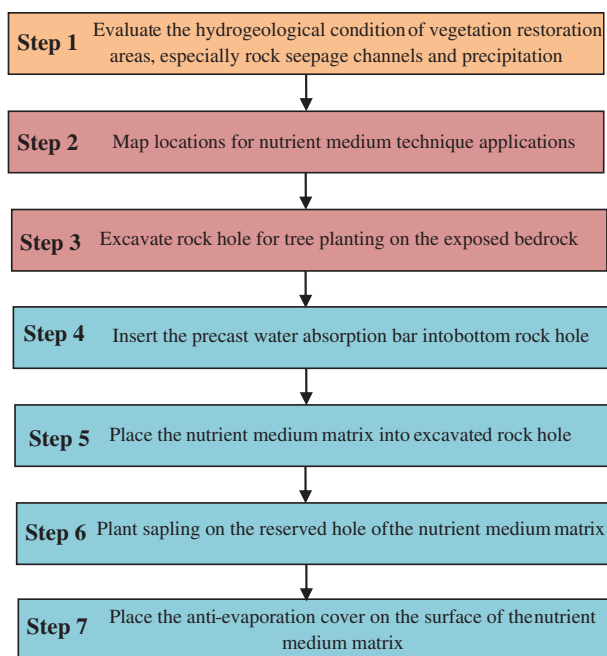
The economy of the nutrient medium technique is an important indicator to determine whether it can be widely used. The total cost of applying nutrient medium technique for planting a sapling can be calculated by the following equation:

$$T = M + P + R + L$$

where T is the total cost, M is the material cost, P is the process cost, R is the drilling cost of the rock hole and L is the labour cost for planting saplings.

According to the market price in Southwest China, the material and process cost are 6 and 10 yuan, respectively, including nutrient medium matrix, water absorption bar and anti-evaporation cover and the drilling cost of the rock hole is 11 yuan and the labour cost for planting sapling is 2 yuan. Therefore, the total cost of applying nutrient medium technique for planting a sapling is approximately 29 yuan. In view of the field application, the layout spacing of the rock hole for planting saplings can be designed as 3×3 m, namely if a nutrient medium matrix needs to be placed within a range of about 10 m^2, then 100,000 nutrient medium matrix are needed for each square kilometre, and the total cost of the nutrient medium matrix for each square kilometre is 2.9 million yuan in accordance with the price of 29 yuan per nutrient medium matrix.

In recent years, the annual increase in the area of KRD in China is 200 km^2 each year. If this technology is used to control KRD, the annual treatment cost is only 750 million yuan.

Step 1	Evaluate the hydrogeological condition of vegetation restoration areas, especially rock seepage channels and precipitation

Step 2	Map locations for nutrient medium technique applications

Step 3	Excavate rock hole for tree planting on the exposed bedrock

Step 4	Insert the precast water absorption bar into bottom rock hole

Step 5	Place the nutrient medium matrix into excavated rock hole

Step 6	Plant sapling on the reserved hole of the nutrient medium matrix

Step 7	Place the anti-evaporation cover on the surface of the nutrient medium matrix

Figure 17. Flow diagram of steps in application of nutrient medium technique.

However, although China has spent more than 10 billion yuan each year to control KRD, the total areas of KRD are still increasing rapidly every year. Therefore, the economy of this technology is better than the traditional tree planting method. In addition, the control of KRD is a long-term process and cannot be solved in a short time, especially in bare KRD areas, and the nutrient medium technique first ensures the survival of the saplings, and then slowly restores the herbaceous plants around the saplings to eventually achieve vegetation restoration of KRD. As shown in Figures 11 and 12, some grasses have grown from the soil at the bottom of the seedlings. Therefore, it is feasible to use this technique to achieve vegetation restoration in bare KRD region.

The nutrient medium technique is not only used in KRD region in China, but also for vegetation restoration in other Karst region in the world, such as Java Island, Indonesia and Campania region, Southern Italy. The steps in application of this technique are shown in Figure 17. The most important first step is to evaluate the local hydro-geological conditions, especially assess the conditions of seepage channels and precipitation conditions. Oktama (2014) reported that the annual rainfall in Java island in 2014 was 2118 mm, and the strata in the area is mainly composed of coral reef limestone and bedded chalky limestone, and the aquifer system has a rapid flow conduits network (Tjahyo and Igor 2016). Due to abundant rainfall in the area and the development of fissures and voids, it satisfies the hydro-geological conditions for the application of this technique. In addition, the Karst in the Campania region, Southern Italy, is composed of calcareous dolomites that are heavily fractured and faulted (Francesco and Angelo 2010). Although there is little rainfall in this Karst area, most of the groundwater flow is controlled by small fissures. Therefore, it is possible to apply this technique to restore vegetation in these regions like Java Island and Campania region. Especially, the design idea of the water absorption bar can also be applied to ecological

restoration in other areas, such as the Loess Plateau, abandoned mines and desertification areas. However, the results of this research have not already been applied in a widespread planting scheme and clearly an integrated demonstration project is required to test their efficacy, and the water absorption properties of water absorption bar should also be incorporated into future studies.

5. Conclusions

A novel approach of vegetation restoration on exposed bedrock areas in Karst rocky desertification (KRD) was developed, which is based on the geological conditions of limestone fissures are extremely developed and rich in fissure water, especially the seasonal rainfall is always abundant in KRD region of Southwest China. The effects of different constituent materials on the water retention and water absorption of nutrient medium mixtures and the plant growth were significant. The moisture content on the 75th day and water absorption rate of No.2 mixture was 19.9% and 1.67 mm/d, respectively, which could be used as optimum mix ratio for producing nutrient medium. The filed results indicated that the trees survived and grew well in the field, and the mixture had less nutrient loss, and the nutrient medium technique could guarantee the survival of trees at early age and sustainable growth at later age. In addition, the hole for water absorption bar is a good channel for the tree seedling roots to extend into the rock mass fissure and to absorb fissure water. This novel approach can retain and absorb water, and saplings do not need artificially supply water and fertiliser in the dry season, and the use of nutrient medium technique to achieve vegetation restoration in KRD region seems to be a feasible option.

Disclosure statement

No potential conflict of interest was reported by the authors.

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