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Effects of Water-Retaining Agent Dosages on Slope-Protection Plants and Soil Nutrients on Rocky Slopes

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Abstract: Rocky slopes lack the necessary conditions for plant growth, i.e., soil and water, making vegetation recovery difficult and necessitating artificial soil conditions for vegetation establishment. Water-retaining agents are essential functional substances for constructing artificial soil on rocky slopes. In this study, the effect of water-retaining agents on the growth of artificial vegetation and soil nutrient loss was investigated by setting different application rates of water-retaining agents (10 g/m^2, 20 g/m^2, 30 g/m^2, 40 g/m^2, and 50 g/m^2). Artificially simulated rocky slope conditions were achieved using the guest soil spraying technology after hanging the net, which provided support for the application of the water-retaining agent. Results showed that the contents of extractable nitrogen (EN), extractable phosphorus (EP), and extractable potassium (EK) in the soil, the number of plant individuals per unit area, plant height, and ground diameter of the water-retaining agent treatment were significantly higher than those of the control group (set up with no water retention as the control group, hereafter "CK"). By contrast, the nutrient content in the runoff fluid was significantly lower than that of CK. The application of the water-retaining agent significantly enhanced the soil's ability to retain water and fertilizer, thus improving the growing environment and plant growth. Under the conditions of this experiment, the application rate of a 40 g/m^2 water-retaining agent is reasonable from the perspectives of economic cost, soil nutrients, and plant growth.

Keywords: rocky slope; artificial vegetation; water-retaining agent; plant; soil nutrients

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1. Introduction

A water-retaining agent is a highly absorbent resin that has a solid ability to repeatedly absorb and release water [1,2]. They have been widely used in agriculture, forestry, soil and water conservation, and ecological restoration [3,4]. As China's infrastructure construction advances, the construction of railways and roads in most areas will result in many exposed rocky slopes. These activities not only destroy vegetation and soil but also tend to cause soil erosion, leading to disasters such as slope failures and debris flows [5,6]. Therefore, revegetation of rocky slopes is essential. The main difficulties in the ecological restoration of rocky slopes include the hardness of the rock surface, their poor water-holding properties, and the lack of soil and water for plant growth [7]. Most rocky slopes are steep, and rainfall erosion can lead to strong runoff and high runoff rates, with the consequent removal of nutrients from the soil occurring [8]. Therefore, the critical point in achieving the ecological restoration of rocky slopes is to improve soil water and nutrient conditions [9]. The application of water retention agents in artificial vegetation restoration on rocky slopes can significantly increase the water content of the soil and reduce soil water loss and the loss of soil nutrients with runoff, thus achieving water and fertility retention [10–12]. At present, research on the application of water retention agents mainly focuses on crop yield, soil physical and chemical properties, and soil moisture content in arid and semi-arid areas [13–15]. Some scholars believe that the appropriate application of water retention agents can significantly increase soil water-holding capacity and improve soil structure and soil nutrient content, thereby increasing potato yields [16]. A study found that soil with water retention agents significantly improved water uptake and utilization by plants, with a more than a 2-fold increase in the germination rate for graminaceous plants and about a 3.5-fold increase in the germination rate for woody plants recorded, but no significant difference was observed in extending plant longevity [17]. Some researchers have proposed that water retention agents promote ryegrass survival and growth under drought conditions by directly or indirectly maintaining ryegrass survival, biomass, relative water content, leaf chlorophyll content, and cell membrane integrity [18]. Although the addition of water retention agents helps to improve the water retention of mulched soil, the amount should be carefully controlled, as excessive amounts can cause the soil to harden and be detrimental to plant growth [19].

At present, there are few studies on the effect of water-retaining agent application on plant growth during rocky slope revegetation and on soil nutrient content in the later stage of rocky slope revegetation. The objective of the work of this experiment was to carry out quantitative research on the use of water retention agents under slope conditions in order to explore the effect of different application rates on artificial vegetation and nutrient loss on rock slopes and to obtain the optimal application rate of water retention agents, providing scientific guidelines for the ecological restoration of rock slopes.

2. Materials and Methods

2.1. Study Sites

The experimental site was located in Shengping Town (31°02′ N, 104°02′ E, 568 m above sea level) in Pengzhou City, Sichuan Province, China. The town's climate type belongs to the humid subtropical monsoon climate, with an annual average temperature of 16.3 °C, annual average rainfall of 1146.5 mm, average annual hours of sunshine of 1131 h, and annual average relative humidity of 79% recorded. The experimental slope had a southward direction, with a gradient of 53° and a slope height of 4 m recorded. The rocky surface was made of 100 cm × 50 cm × 10 cm slabs, and runoff collection devices were installed at the corners of the slope (Figure 1). Each plot was 1.5 m wide, with 18 sloping test plots employed. The plots were separated by 35 cm high PVC panels. Soil mixed with a water retention agent, grass seed, and a fertilizer compound were sprayed onto the artificial rocky slopes using a guest soil spraying technique.

2.2. Experimental Design

2.2.1. Soil Information

Rocky slopes are unsuitable for plant growth, and it is necessary to ensure that rocky slope revegetation is successful. Guest soil spraying technology, a widely applicable and efficient vegetation building technique, is widely used in China in the road and railway greening industries and in the biological protection of river banks. Artificial soil used in guest soil spraying can improve the soil conditions and nutrients on rocky slopes and enable rapid greening in harsh scenarios such as rocky slopes. Therefore, guest soil spraying, with a 15 cm soil mixture thickness, was used in this study for revegetation. Specifically, in May 2019, the seeds (15 g/m^2) were mixed with peat (5 kg/m^2), compound fertilizer (nitrogen, phosphorus and potassium content 15:15:15, 20 g/m^2), and the water-retaining agent. The physicochemical properties of artificial soil used for covering the rocky slope are given in Table 1. Observations and measurements of various traits were carried out in May 2020 (1 year after sowing) and May 2021 (2 years after sowing). Other plants were removed weekly to allow for accurate observations of the growth of the model species, i.e., *Amorpha fruticose (A. fruticosa)*.

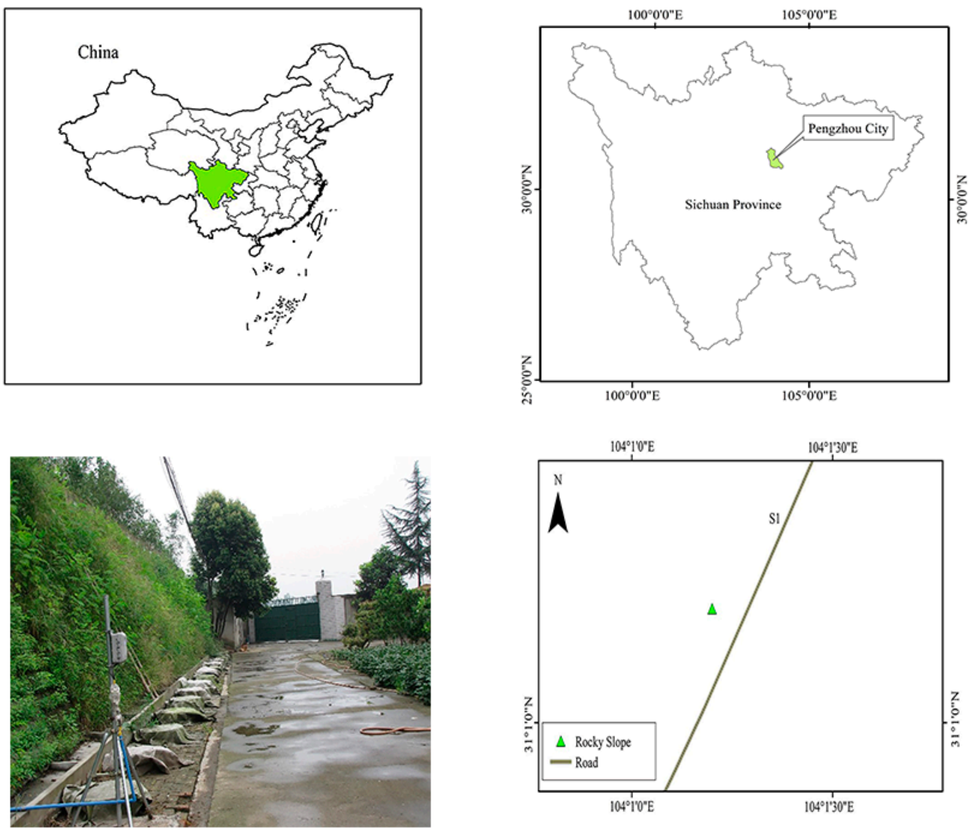

Figure 1. Location information of the study sites.

Table 1. Physicochemical properties of artificial soil used for covering the rocky slope.

Organic Matter (g/kg)	Extractable P (mg/kg)	Extractable K (mg/kg)	Extractable N (mg/kg)	Bulk Density (g/cm^3)
24.16	71.22	120.66	153.28	1.33

2.2.2. Experimental Shrub Species

This study used *A. fruticosa*, a typical slope protection plant species widely used in southwest China, as the model species. *A.* fruticosa has high drought, moisture, and salinity tolerance. It has a substantial slope-fixing capacity, as it grows fast with a relatively well-developed root system after seedling emergence [20].

2.2.3. Water Retention Agent Treatment

The water-retaining agent used in this experiment was starch-grafted potassium acrylate, which is entirely degradable in soil. It is a super absorbent polymer with a particle diameter of 50 mesh and a water absorption multiplier (0.9% brine) of 50 times. In order to explore the effects of water-retaining agents on soil nutrients and plant growth, five water retention treatments (10 g/m^2, 20 g/m^2, 30 g/m^2, 40 g/m^2, and 50 g/m^2) were set up, with no water retention used as the control group (hereafter "CK"). Each water retention treatment had three replicates, adding up to 18 slope plots.

2.3. Measurements and Methods

2.3.1. Plant Growth Parameters

In early May of 2020 and 2021, the number of plants was counted in each trial plot to calculate the number per unit area. The number of *A. fruticose* plants was counted by the direct counting method. Preservation rate of the number of plants per unit area was calculated using the following equation:

$$\frac{\text{Number of plants per unit area in Year 1} - \text{number of plants per unit area in Year 2}}{\text{Number of plants per unit area in Year 1}}$$

At the same time, ten individual *A. fruticose* plants were randomly selected from each replicated plot, and their plant heights were measured with a steel tape measure (accuracy 0.1 cm). The ground diameter was measured with an electronic vernier caliper (accuracy 0.01 mm).

2.3.2. Nutrient Content in the Soil

Nutrient content in the soil was measured in early May of 2020 and 2021. The alkaline solution diffusion method determined soil extractable nitrogen (EN) [21]. The extractable phosphorus (EP) [22] was measured using the $NaHCO_3$ leaching with molybdenum-antimony anticolorimetric method. The extractable potassium (EK) was extracted with acetic acid and measured by flame photometry [23].

2.3.3. Nutrient Content in Runoff Fluid

After measuring the volume of runoff liquid in the collection cylinders, the liquid in the collection cylinders was stirred well, and three leachate samples were collected from each collection cylinder. One liter of each sample was used for the determination of nitrogen, phosphorus and potassium contents. Specifically, samples were placed in polyethylene bottles and marked and stored in a refrigerator at 0 °C, and the analysis of total nitrogen, total phosphorus, and total potassium nutrients was conducted within one week. The total nitrogen of the water sample was determined by UV spectrophotometry using alkaline potassium persulfate nitrate, the total phosphorus by molybdenum antimony anti-colorimetric method using potassium persulfate, and the total potassium by direct filtration-flame photometer method.

2.4. Statistical Analysis

All data were processed and plotted using Microsoft Excel 2019; all variables were described using means and standard deviations. One-way analysis of variance (ANOVA) was performed on the data using SPSS 22.0 software. Comparisons among treatments were based on Duncan's multiple range test at the 0.05 probability level.

3. Results

3.1. Effects of Water Retention Agent on Nutrients in the Soil

The nutrient content in the soil was significantly affected by the water-retaining agent treatment (Table 2). Compared with CK, the contents of EN, EP, and EK were increased significantly after the use of the water-retaining agent (Table 2), indicating that the water-retaining agent significantly maintained soil EN contents. Soil EP and EK contents between the water retention dosages of 30 g/m^2, 40 g/m^2, and 50 g/m^2 were not significantly different ($p > 0.05$), but were significantly higher than those of other treatments and CK ($p < 0.05$). Similarly, soil EN contents between the water retention dosages of 40 g/m^2 and 50 g/m^2 did not differ significantly ($p > 0.05$), but were significantly higher than those of other treatments and CK ($p < 0.05$).

Table 2. Effect of water-retaining agent dosages on soil nutrient content.

Dosage of Water-Retaining Agent (g/m^2)	Extractable N (mg/kg)		Extractable P (mg/kg)		Extractable K (mg/kg)	
	May 2020	May 2021	May 2020	May 2021	May 2020	May 2021
0	29.39 ± 1.26 e	17.64 ± 0.77 e	27.62 ± 1.03 d	16.59 ± 0.64 d	59.38 ± 1.11 d	35.63 ± 0.67 d
10	43.53 ± 1.55 d	26.12 ± 0.93 d	34.39 ± 0.73 c	20.63 ± 0.44 c	69.72 ± 1.78 c	41.88 ± 1.16 c
20	52.29 ± 0.85 c	31.38 ± 0.51 c	41.53 ± 1.12 b	24.93 ± 0.68 b	76.54 ± 2.03 b	45.93 ± 1.21 b
30	63.44 ± 1.11 b	38.06 ± 0.66 b	46.33 ± 0.44 a	27.80 ± 0.28 a	83.12 ± 1.14 a	49.87 ± 0.68 a
40	66.07 ± 1.29 a	39.64 ± 0.78 a	46.87 ± 0.59 a	28.13 ± 0.37 a	82.44 ± 1.15 a	49.47 ± 0.70 a
50	65.69 ± 0.99 a	39.41 ± 0.59 a	47.22 ± 0.95 a	28.34 ± 0.56 a	82.40 ± 0.83 a	49.44 ± 0.50 a

Values with different letters indicate significant differences between treatments at $p < 0.05$.

The loss of soil nutrients in each group in the first year (i.e., the original value of soil nutrients minus one year after sowing) and in the second year (i.e., one year after sowing minus two years after sowing) are shown in Figures 2–4. The loss of soil EN in Year 1 was 10.54, 6.30, 4.83, 3.54, 3.30, and 3.33 times higher than the loss in Year 2 for each group, and the difference between the water-retaining agent dosages of 40 g/m^2 and 50 g/m^2 was not significant ($p > 0.05$) (Figure 2).

The loss of EP in Year 1 was 3.95, 2.68, 1.79, 1.34, 1.30, and 1.27 times greater than the loss in Year 2 for each treatment group, respectively, and the differences between the water-retaining agent dosages of 30 g/m^2, 40 g/m^2 and 50 g/m^2 were not significant ($p > 0.05$) (Figure 3).

The loss of EK in Year 1 was 2.58, 1.83, 1.44, 1.13, 1.16, and 1.16 times higher than the loss in Year 2 for each treatment group, respectively, while the differences between water retention dosages of 30 g/m^2, 40 g/m^2 and 50 g/m^2 were not significant ($p > 0.05$) (Figure 4).

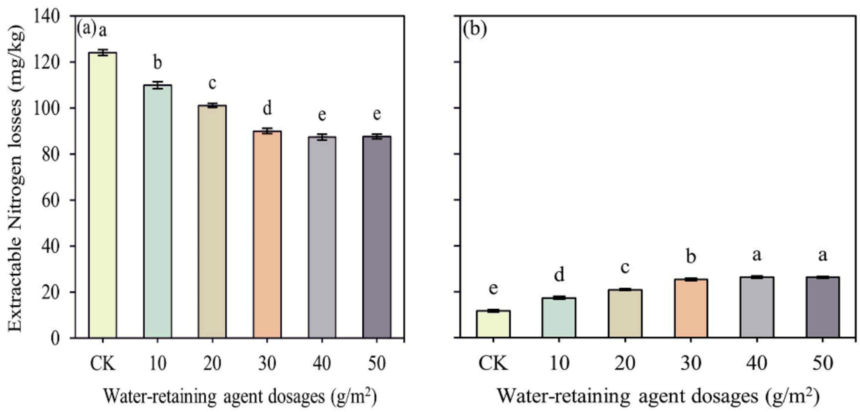

Figure 2. The effect of dynamic changes of soil nutrient loss under different dosages of water-retaining agents. (**a**) Data for EN (the loss of EN in each group in the first year); (**b**) data for EN (the loss of EN in each group in the second year). Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

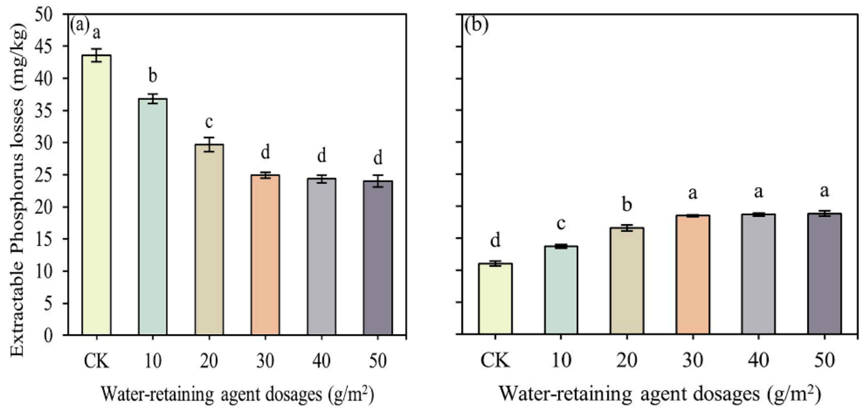

Figure 3. The effect of dynamic changes of soil nutrient loss under different dosages of water-retaining agents. (**a**) Data for EP (the loss of EP in each group in the first year); (**b**) data for EP (the loss of EP in each group in the second year) Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

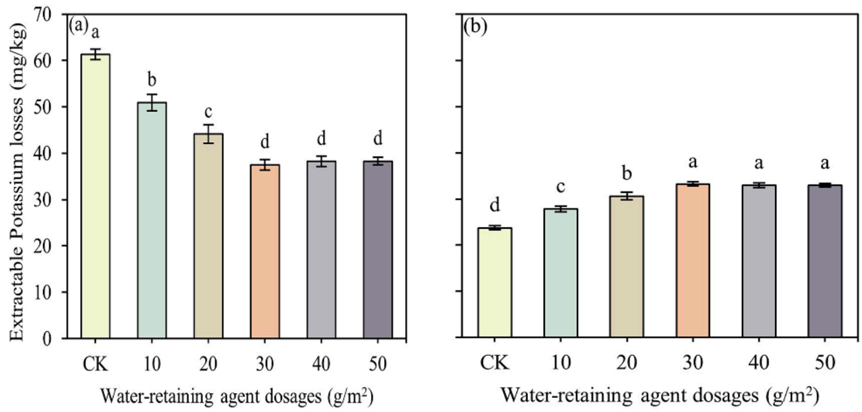

Figure 4. The effect of dynamic changes of soil nutrient loss under different dosages of water-retaining agents. (**a**) Data for EK (the loss of EK in each group in the first year); (**b**) data for EK (the loss of EK in each group in the second year). Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

3.2. Effects of Water Retention Agent on Nutrients in the Runoff Fluid

In two separate measurements conducted in 2020 and 2021, compared with CK, total nitrogen, potassium, and phosphorus in the runoff solution were significantly lower after the use of the water-retaining agent (Table 3), indicating that the water-retaining agent significantly reduced the nutrient content of the runoff solution. Total potassium and total phosphorus in the runoff solution between the water-retaining agent dosages of 40 g/m^2 and 50 g/m^2 were not significant ($p > 0.05$), but were significantly higher than those of other treatments and CK. Total nitrogen in the runoff solution was significantly higher than that of other treatments and CK at 50 g/m^2 of the water-retaining agent in the first year after sowing. Total nitrogen values in the runoff solution were not significantly different ($p > 0.05$) between 40 g/m^2 and 50 g/m^2 of the water-retaining agent in the second year after sowing, and these were significantly higher than the total nitrogen values of other treatments and CK.

Table 3. Effect of water-retaining agent dosage on nutrient content in runoff fluid.

Dosage of Water-Retaining Agent (g/m^2)	Total N in Runoff Fluid (g)		Total K in Runoff Fluid (g)		Total P in Runoff Fluid (g)	
	May 2020	May 2021	May 2020	May 2021	May 2020	May 2021
0	47.06 ± 1.30 a	18.82 ± 0.52 a	32.39 ± 1.58 a	12.96 ± 0.63 a	18.78 ± 1.00 a	7.51 ± 0.40 a
10	36.18 ± 2.31 b	14.47 ± 0.93 b	22.53 ± 0.60 b	9.01 ± 0.24 b	14.35 ± 0.43 b	5.74 ± 0.17 b
20	26.70 ± 0.67 c	10.68 ± 0.27 c	18.69 ± 0.69 c	7.48 ± 0.28 c	12.42 ± 0.58 c	4.97 ± 0.23 c
30	20.55 ± 0.67 d	8.16 ± 0.18 d	16.86 ± 0.58 d	6.74 ± 0.23 d	10.80 ± 0.72 d	4.32 ± 0.29 d
40	16.33 ± 0.79 e	7.43 ± 0.13 de	14.93 ± 0.64 e	5.94 ± 0.21 e	9.54 ± 0.38 e	3.46 ± 0.16 e
50	12.79 ± 1.04 f	7.29 ± 0.17 e	13.90 ± 0.27 e	5.76 ± 0.13 e	8.45 ± 0.32 e	3.38 ± 0.12 e

Values with different letters indicate significant differences between treatments at $p < 0.05$.

Figures 5–7 show the nutrient loss from Year 1 to Year 2 due to runoff for each group, i.e., the value in Year 1 minus the value in Year 2. As shown in Figure 5, the total nitrogen loss from Year 1 to Year 2 between differing dosages was significantly different, with CK having the highest loss of total nitrogen ($p < 0.05$).

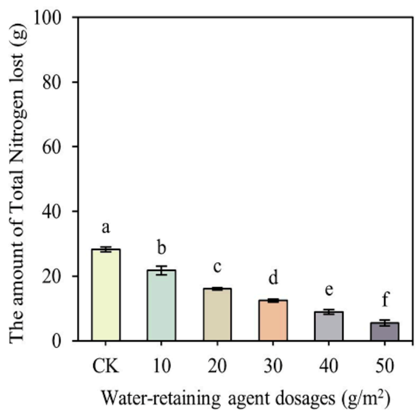

Figure 5. Dynamics of total nutrients in runoff fluid under different dosages of water-retaining agents. Data for the amount of total nitrogen loss (the amount of total nitrogen loss from Year 1 to Year 2 of each group, due to runoff). Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

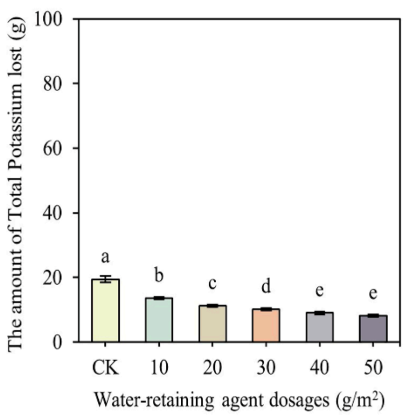

Figure 6. Dynamics of total nutrients in runoff fluid under different dosages of water-retaining agents. Data for the amount of total potassium loss (the amount of total potassium lost from Year 1 to Year 2 of each group due to runoff). Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

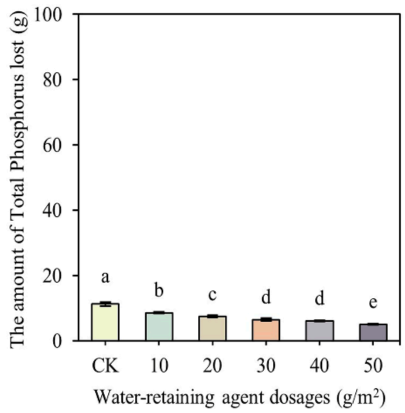

Figure 7. Dynamics of total nutrients in runoff fluid under different dosages of water-retaining agents. Data for the amount of total phosphorus loss from Year 1 to Year 2 of each group due to runoff). Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

As shown in Figure 6, the amount of total potassium loss from Year 1 to Year 2 due to runoff in CK was also the highest at the water retention agent dosage of 50 g/m^2. The difference between the water-retaining agent dosages of 40 g/m^2 and 50 g/m^2 was not significant ($p > 0.05$).

Figure 7 shows the amount of total phosphorus loss from Year 1 to Year 2 due to runoff. Again, CK had higher total phosphorus loss than any other dosage treatments. The difference between the water retaining agent dosages of 30 g/m^2 and 40 g/m^2 was not significant ($p > 0.05$).

3.3. Water Retention Agent on Plant Growth

Table 4 shows that in May 2020 and May 2021, compared with CK, the number of plants per unit area, plant height, and ground diameter increased significantly after the water-retaining agent was used, indicating that the water-retaining agent significantly promoted the growth of *A. fruticosa*. In May 2020, the number of plants per unit area and the plant height were not significantly different between 30 g/m^2, 40 g/m^2, and 50 g/m^2 ($p > 0.05$), but were significantly higher than those of other treatments and CK. The same pattern was also found for the ground diameter of plants grown on slop plots with 40 g/m^2 and 50 g/m^2 of the water-retaining agent ($p > 0.05$). In May 2021, the number of plants per unit area, and the plant height and ground diameter of *A. fruticosa* reached the maximum in the treatment of 50 g/m^2 super absorbent polymer, which was significantly higher than those recorded for the other treatments and CK.

Table 4. The effect of water-retaining agent dosage on plant growth.

Dosage of Water-Retaining Agent (g/m^2)	Number of Plant Individuals Per Unit Area		Plant Height (cm)		Plant Ground Diameter (cm)	
	May 2020	May 2021	May 2020	May 2021	May 2020	May 2021
0	32 ± 1.00 d	20 ± 1.00 f	96 ± 1.00 d	106 ± 1.00 f	1.3 ± 0.06 d	2.1 ± 0.06 f
10	37 ± 1.00 c	25 ± 1.00 e	104 ± 1.00 c	113 ± 2.00 e	1.7 ± 0.06 c	2.5 ± 0.06 e
20	42 ± 1.00 b	30 ± 1.00 d	113 ± 1.00 b	121 ± 0.58 d	1.8 ± 0.06 c	2.6 ± 0.06 d
30	47 ± 0.58 a	35 ± 1.00 c	118 ± 1.00 a	127 ± 0.58 c	2.0 ± 0.10 b	2.8 ± 0.06 c
40	46 ± 1.00 a	39 ± 1.00 b	118 ± 1.00 a	133 ± 1.00 b	2.2 ± 0.06 a	3.2 ± 0.06 b
50	45 ± 1.53 a	41 ± 0.58 a	119 ± 2.08 a	139 ± 2.08 a	2.2 ± 0.10 a	3.5 ± 0.06 a

Values with different letters indicate significant differences between treatments at $p < 0.05$.

Figure 8 shows the difference between Year 1 and Year 2 in terms of the number of plants per unit area for each group. The number of plants per unit area in Year 2 was reduced by 37.50%, 32.43%, 28.57%, 25.53%, 15.22%, and 8.89%, respectively, compared to Year 1. The difference between CK and the water retention agent dosages of 10 g/m^2, 20 g/m^2, and 30 g/m^2 was the largest difference between the four groups, although this was not significant ($p > 0.05$), and the difference for the water retention agent dosage of 50 g/m^2 was the smallest. This suggests that the preservation rate of *A. fruticosa* was significantly higher at 50 g/m^2 of water retention than for other treatments and CK.

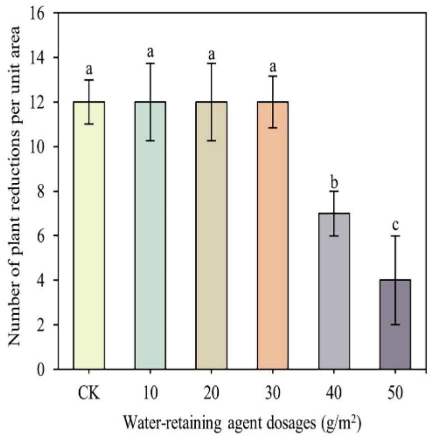

Figure 8. Variation in plant growth with different dosages of the water-retaining agent. Data for the number of plant reductions per unit area. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

Figure 9 shows the difference in plant height between Year 1 and Year 2 for each group. Specifically, no significant differences between CK and the water retention dosages of 10 g/m^2, 20 g/m^2, and 30 g/m^2 were observed; however, plants in the above four treatments were significantly shorter than those treated with the water retention dosages of 40 g/m^2 and 50 g/m^2. The largest plant height was observed for the water retention dosage of 50 g/m^2, followed by the water retention dosage of 40 g/m^2. This indicates that the mean plant height growth rate was significantly higher at 50 g/m^2 and 40 g/m^2 than in other treatments and CK.

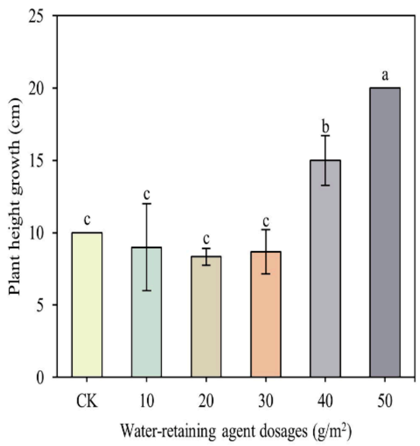

Figure 9. Variation in plant growth with different dosages of the water-retaining agent. Data for plant height growth. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

Figure 10 shows the difference between Year 1 and Year 2 in terms of the ground diameter. The plant diameter of the 50 g/m^2 group was the largest, while no significant difference was found between the other treatment groups (i.e., CK and 10 g/m^2, 20 g/m^2, 30 g/m^2, and 40 g/m^2), indicating that the plants grew faster in the 50 g/m^2 of water-retaining agent treatment than in other treatments and CK.

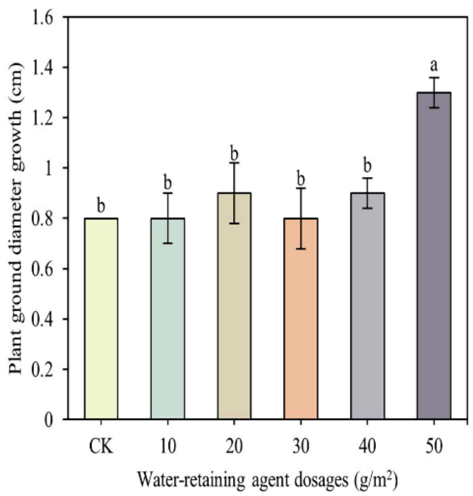

Figure 10. Variation in plant growth with different dosages of the water-retaining agent. Data for plant ground diameter growth. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

4. Discussion

Previous studies have shown that water retention agents can fix and slowly release soil nutrient ions already dissolved in water in different ways, such as wrapping and complexing [24]. The structural properties of the molecules of the water retention agent themselves can also adsorb nutrients [25]. The results of this study showed that compared to CK (no water retention agent application), soil hydrolytic nitrogen, effective phosphorus, and fast-acting potassium contents increased significantly with increases in water retention agent dosage, indicating that the application of water retention agents can significantly enhance soil nutrient content under slope conditions. Some studies have shown that for different crops, the optimal application amounts of water retention agents are also different [26]. The application amounts of water retention agents do not simply follow the “the more, the better” pattern; after a certain amount, their effects have been found to increase to a limited extent. The results of this experiment showed that increases in the EP and EK contents of the slope soil after the application of the water retention agent dosage of 30 g/m^2 were no longer obvious, while the threshold was 40 g/m^2 for EN content. Research has demonstrated that the application of water retention agents significantly improves soil ability and water conservation in two main ways. Firstly, water-retaining agents, when applied to the soil, can absorb water and gradually swell to form a protective film of soil, thus reducing the splash of rainwater on the soil surface and protecting the surface soil [27,28]. Secondly, the moderate application of water retention agents has a binding effect on the soil, which is manifested by the adsorption of micro-agglomerates around the water retention agent, thus forming large agglomerates. This can achieve the purpose of reducing soil loss with runoff and therefore significantly reduce soil nutrient loss due to soil erosion [29]. Some studies have shown that water retention agents improved soil fertility in mining areas, significantly increasing effective nitrogen, effective phosphorus, effective potassium, and soil organic matter [30]. Our experimental study showed that the total amount of nitrogen, phosphorus, and potassium in the runoff solution decreased significantly compared to CK with increases in the water retention agent dosage, both in Year 1 and Year 2.

Some scholars have shown that when a water retention agent is applied to the soil around a plant’s roots, the water retention agent will rapidly absorb water from the soil, thus reducing deep infiltration losses. Then, the water is gradually released to the plants. This process improves the efficiency of soil water use and thus ensures the development of the above-ground part of the plants and their root systems [31–33]. The results of this experiment suggested that the number of plants per unit area, and the plant height and ground diameter of *A. fruticosa* showed an increasing trend with increases in water retention agent dosage, both in Year 1 and Year 2. This is because the application of water retention agents can reduce the soil bulk density and increase soil permeability [34], thus improving the growth environment of plant roots while extending the duration of fertilizer supply more so than with CK. As a result, the leaching and loss of soil nutrients were significantly reduced, providing sufficient nutrient resources for plant growth in rocky slope habitats [35,36]. Moreover, the application of water retention agents can enhance the water holding capacity of the soil, and better moisture conditions also make the plant survival rate higher and more robust [37]. During the experiment, we also analyzed the soil water content. Compared with the control group (CK), the average monthly soil water content increased by 21.98%, 41.21%, 59.34%, 78.57%, and 91.21%, respectively. The difference between the groups was significant ($p < 0.05$) and showed an increasing trend with the increases in water retention agent dosage, which can be explained from the perspective of water condition maintenance. The increasing amount of water retained by the water retention agents with each group was significant ($p < 0$ 05), which could have enhanced plant growth. Some scholars have shown that the primary forms of vegetation cover that prevent soil erosion and nutrient loss are the crown interception of rainfall [38], root systems that improve soil erosion resistance, and plant roots that improve soil rainwater infiltration. The higher the vegetation cover, the more the runoff is impeded. Therefore, the slope runoff rate tends to slow down as the vegetation increases. The results of this experiment showed that in the first year of water retention application, soil nutrient loss in all groups was higher than that in the second year. The reason for this was that in the first year, *A. fruticosa* did not fully develop, and the vegetation cover was not high in the pre-growth period, resulting in faster soil nutrient loss from the rocky slopes. In the second year, *A. fruticosa* reached its full growth, so the soil nutrient loss in this year was lower than that in the first year. The results of this study also showed that the difference in soil nutrient content and the gradient of total nutrient difference in the runoff solution were different between Year 1 and Year 2, which may have been due to decreases in the performance of the water retention agent over time. Previous studies have shown that with increases in the number of water absorption and release cycles, the water retention agent water absorption capacity shows a decreasing trend [39–41]. In this study, such a trend resulted in a decrease in the ability of the water retention agent to adsorb nutrient molecules or ions from soil nutrients, thus leading to the significant difference in various indicators between Year 1 and Year 2, e.g., the decreases in the number of plants per unit area, plant height growth rate and ground diameter growth rate compared to Year 1. The soil nutrient content affected the recovery of vegetation [42]. In line with the results of previous studies, CK had the lowest vegetation cover and the worst recovery of vegetation.

Ecological restoration projects on rocky slopes should also focus on the effect of vegetation restoration; they also need to pay attention to the economic costs [43]. The price of the water-retaining agent used in this experiment was 0.03 CNY/g. In other words, the cost of the water-retaining agent dosage of 40 g/m^2 was 0.3 CNY more per square than that of the 30 g/m^2 dosage. However, the final results of this experiment show that the water-retaining agent dosage of 40 g/m^2 performed significantly better than the 30 g/m^2 dosage in terms of EN content, plant number per unit area, plant height, and ground diameter. The total nitrogen, potassium, and phosphorus contents in the runoff solution for the dosage of 40 g/m^2 were significantly lower than those for the water-retaining agent at 30 g/m^2. The overall comparison showed that the water-retaining agent at 40 g/m^2 was more effective than that at 30 g/m^2. Compared with the water-retaining agent dosage of 50 g/m^2, the water retention agent dosage of 40 g/m^2 was 0.3 CNY cheaper per square, and the economic cost of the 50 g/m^2 dosage was higher than that of the 40 g/m^2 dosage.

Although there were differences in the number of plants per unit area, plant height, and ground diameter, there were no significant differences between the soil EN, EP, and EP contents and the total nitrogen, potassium and phosphorus contents in the runoff solution. Due to the combination of economic costs and combined effects, a water-retaining agent dosage of 40 g/m^2 may be more suitable for practical applications.

5. Conclusions

(1) The use of a water-retaining agent can enhance the EN, EP, and EK contents of rocky slope soils to various degrees, and reduce the EN, EK, and EP contents in runoff fluids, thus achieving the purpose of reducing soil loss from rocky slopes and contributing to the function of soil nutrients under rocky slope conditions. However, its function did not increase indefinitely with increases in the water-retaining agent dosage.
(2) The water-retaining agent at 40 g/m^2 and 50 g/m^2 increased the number of plants that survived in Year 2, increased the plant height and ground diameter, and improved the survival rate and growth of artificial vegetation on rocky slopes. These dosages also improved the coverage of artificial vegetation and the growth of the individual plants under rocky slope conditions. However, their functions did not increase indefinitely with increases in the water-retaining agent dosage.
(3) Considering the economic and cost factors, together with performance factors (i.e., soil nutrient and runoff losses, plant preservation rate, and growth conditions), the water-retaining agent dosage of 40 g/m^2 is reasonable under the present test conditions, since it performed relatively well in our study under rocky slope conditions.

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