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Effects of Film Mulching on Plant Growth and Nutrients in Artificial Soil: A Case Study on High Altitude Slopes

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Abstract: Vegetation restoration on slopes is generally difficult, especially in high altitude areas since the environment has dramatically changing weather conditions that are not suitable for plant growth. In this study, the potential of film mulching for vegetation restoration in such environments and plant growth and nutrients in artificial soil on slopes in high altitude areas were determined. Experiments were carried out in Jiuzhaigou County, Sichuan Province, to determine plant growth and nutrients in artificial soil on slopes under six different coverage rates (40%, 50%, 60%, 70%, 80% and 90%). Results showed that in each observation period, plant height, ground diameter and contents of EN, EP and EK in the soil of the film mulching treatment were significantly higher than those of the control, while the number of plant individuals per unit area was significantly lower than that of the control. When the coverage rate was 90%, plant height, ground diameter, biomass and nutrient contents in the soil were all higher than those under the other five treatments. Overall, our study suggested that applying film mulching technology when performing vegetation restoration on slopes in high altitude areas is promising, since it can promote plant growth and preserve soil fertility.

Keywords: coverage rate; film mulching; high altitude areas; slope; plant; nutrients

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1. Introduction

In the process of human engineering activities, a large number of slopes are usually excavated [1–3]. The formation of cut slopes causes great disturbance to the ecosystem, such as the removal of natural soil, the destruction of natural vegetation and the degradation of biodiversity in mountainous areas [4–6]. Such disturbance is increased by additive effects in high altitude areas with a long sunshine duration, an extremely low temperature, constantly changing weather conditions, and concentrated rainfall. The ecosystem in these areas is very fragile and difficult to recover once damaged [7]. Rocky slopes simply do not have the soil environment necessary for the growth of most plant species, nor do they have the proper moisture and sufficient nutrients to meet the needs of the plant growth of most plant species [8]. Therefore, there is barely any plant growing on exposed rocky slopes for a long period of time, which is not conducive to the restoration of the ecosystem and poses severe threats to traffic safety [9]. In recent years, with a growing awareness of environmental protection, the vegetation recovery of rocky slopes has been increasingly discussed, and it is urgent to take appropriate measures to repair these excavated slopes [10].

Cut slopes in high altitude areas are generally covered by a thin and loose layer of soil that could readily be washed away when exposed to water, as well as variable and complex climate environments where slopes are located [11,12]. Due to the above mentioned

characteristics, natural disasters, such as landslides and debris flow, are more likely to occur on such slopes [13]. As a result, vegetation restoration should be performed. How to reduce the environmental constraints (e.g., temperature and moisture) for vegetation growth and mitigate the erosion of slope soil are urgent problems to be solved [14]. Previous studies have found that film mulching technology plays an important role in regulating soil temperature, maintaining soil moisture and inhibiting weed growth [15–17], which can create favorable conditions for vegetation growth and, thus, potentially be of great significance for slope vegetation restoration in high altitude areas [18]. It has also been shown that degradable film mulch has the same effect as traditional plastic film mulch in reducing soil evaporation and balancing ground temperature [19–21]. Moreover, it is an ecofriendly material that can provide carbon and nutrients to the soil after degradation [22].

Previous studies on slope properties in high altitude areas have mainly focused on the improvement of artificial soil substrates [23,24], whereas very few studies have explored vegetation restoration and nutrient contents in the soil during the later stages of the process. In addition, the research on the quality and properties of soil mainly focused on wetlands or degraded karst, but only a minor focus was on the high altitude area [25–27]. Film mulching has long been used in agricultural production, and it has become a widely used agricultural technique in arid and semiarid areas [28–30]. However, there are few studies on its application in slope vegetation restoration. In recent years, there has been an increasing demand for reducing the use of plastic film because of potential environmental and ecological risks; degradable film has been used as an alternative to plastic film [31,32]. This study aimed to investigate the effects of film mulching on plant growth and nutrients in artificial soil of slopes in high altitude areas, and to provide theoretical support for the effective guarantee of slope vegetation restoration in high altitude areas.

2. Materials and Methods

2.1. Study Sites

Jiuzhaigou County is located in the transition zone between the Qinghai–Tibet Plateau and Sichuan Basin, administratively belonging to the Aba Tibetan and Qiang Autonomous Prefecture of Sichuan Province. Its latitude ranges from 32°53′–33°43′ N, while the longitude ranges from 103°27′–104°26′E, with a total area of 5286 km^2. The county's elevation range is 1100–4800 m. The climate type belongs to the plateau humid climate, with an annual average temperature of 12.7 °C, annual average rainfall of 550 mm, an annual average sunshine duration of 1600 h, and an annual average relative humidity of 65%.

The experimental slope was a soil–rock slope about 2860 m above sea level, covering an area of about 2600 m^2, with a gradient of 48° and a slope height of 10 m. The slope had a direction of 30° south of east (S30E), with an extremely thin layer of topsoil (Figure 1). The physicochemical characteristics of the topsoil are given in Table 1.

Table 1. Physicochemical properties of topsoil used for covering the slope.

Bulk Density (g cm^{-3})	Organic Matter (g kg^{-1})	Extractable N (mg kg^{-1})	Extractable P (mg kg^{-1})	Extractable K (mg kg^{-1})
1.32	24.34	153.66	72.19	121.49

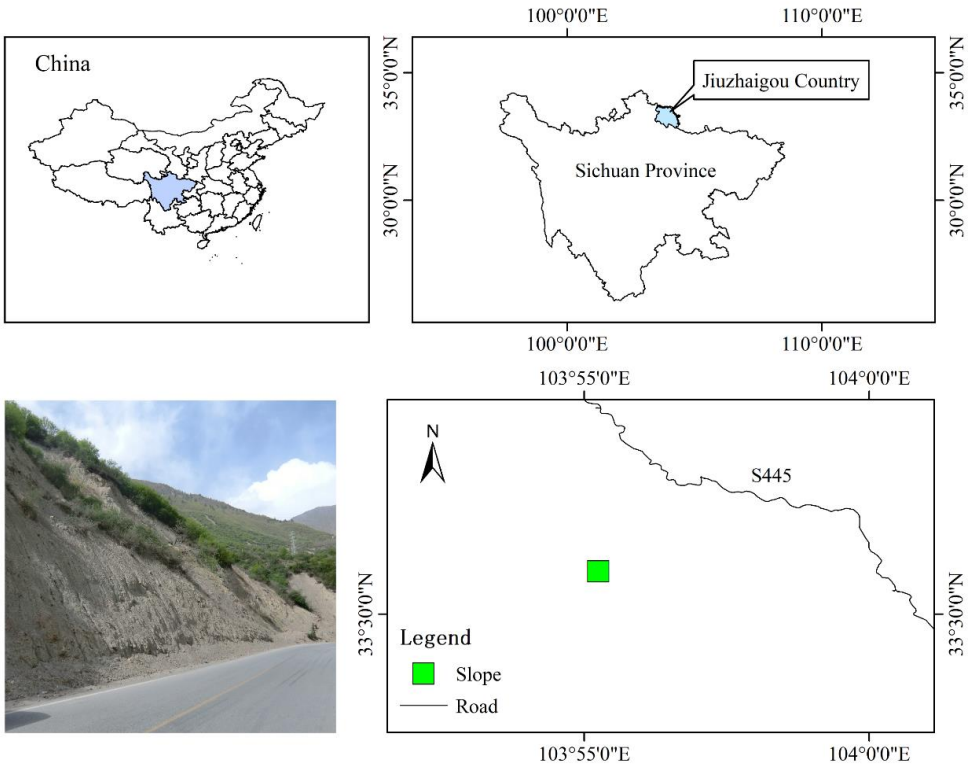

Figure 1. Location information of the study area.

2.2. Experimental Design

2.2.1. Soil Information

Slopes with conditions mentioned above were not suitable for plant growth and, thus, it was necessary to ensure successful soil reclamation. Outside soil spray seeding (OSSS), as a broadly applicable and highly efficient technique, is used widely for road cut revegetation in China, and the artificial soil used in OSSS can improve slope soil conditions and nutrients, and help promote plant growth and succession [33]. Therefore, outside soil spray seeding (OSSS) was used for slope vegetation restoration with a thickness of 12 cm soil mixture. Specifically, on 8 May 2019, OSSS of the experimental slope was carried out using the HKP-125 soil spraying machine of Henan Hengrui Machinery Manufacturing Co., Ltd. The soil mixture was made of surface soil excavated during local road construction, peat, polyacrylamide, compound fertilizer and seeds. The recipe is as follows per 1000 g dry soil: 30 g peat (dry weight), polyacrylamide (0.5 g), compound fertilizer (potassium dihydrogen phosphate, 0.3 g), and plant seeds (0.2 g).

2.2.2. Experimental Grass Species

Selecting suitable plant species for establishing plant communities on slope surfaces is one of the important tasks in slope revegetation [34,35]. In this study, *Caragana erinacea*, a typical and widely distributed alpine steppe desert species in Xizang and western Sichuan, was selected. Long term adaptation to the alpine habitat has made *Caragana erinacea* capable of dealing with high drought stress.

2.2.3. Film Mulching Treatment

A black PBAT (Polybutylene adipate terephthalate) degradable film provided by Zhejiang University was used for film mulching, and its degradation time under natural conditions was 4–5 months. The film has a thickness of 0.03 mm, a tensile load of 3.85 N/m^2, and a relative degradable rate of 96% after 150 days.

In order to explore the effects of film mulching on plant growth and nutrients in the soil, six coverage rates (40%, 50%, 60%, 70%, 80%, and 90%) along the slope were set horizontally with bare soil as the control group (hereafter "CK"). The appearance of the slope after covering it with the degradable mulch is shown in Figure 2. Different coverage rates of film mulching were achieved by evenly cutting circular openings with a diameter of 1 cm across the film. Such openings also ensured rainfall infiltration. As shown in Figure 3, each coverage rate treatment had three replicates and each replicate covered an experimental area of 50 m^2, adding up to a total of 21 experimental plots and a 1050 m^2 experimental area. After spraying, the soil was watered to saturation, and immediately covered with PBAT degradable film with different coverage rates (tightly attached to the soil surface). The film was completely degraded by October 2019.



Figure 2. Distance view of slope was covered with degradable mulch.

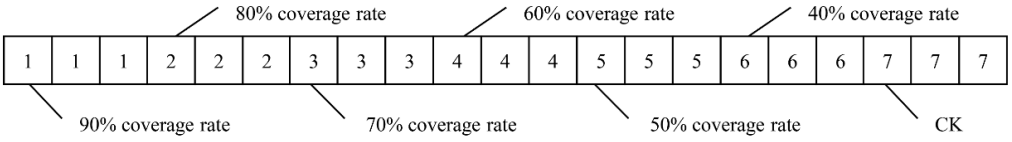

Figure 3. The scheme for the experimental design. There were seven treatments, including the control group. Within each treatment, there were three replicate plots, adding up to 21 plots in total, in which eighteen were covered with PBAT degradable film (black) while three were control (uncovered).

2.3. Measurements and Methods

2.3.1. Plant Growth Parameters

In early June 2019, early October 2019 and early May 2020, the number of plants was counted in each test plot to calculate the number of plants per unit area. The plant height of 10 randomly labeled plants in each test plot was measured with a tape measure (accuracy 1 mm), and then the average plant height was calculated [36].

A small quadrat was set up in each replicate plot to determine plant biomass (the sum of aboveground and underground biomass) using the harvesting method in early October 2019 (1 m × 1 m) and early May 2020 (2 m × 2 m), respectively. The plants were uprooted from each quadrat carefully and taken to the laboratory. The collected plants were dried in an oven at 105 °C for 30 min and then at 65~75 °C for 48 h. After cooling, plants were taken out and weighed [37].

In early May 2020, the ground diameters of 10 randomly labeled plants were measured in each replicate, adding up to 210 plants in total [38]. The ground diameter of the stem

was measured as 1 cm above the soil surface with a vernier caliper (accuracy 0.01 mm). The diameters of plants in each replicate were averaged to obtain the mean ground diameters.

2.3.2. Nutrient Contents in the Soil

Nutrient contents in the soil were determined in early June 2019, early October 2019, and early May 2020. Three 4 m × 4 m quadrats were set in each test plot, and the soil samples were air dried, removed of impurity, and screened for determination. The content of extractable nitrogen (EN) in the soil was measured using an alkaline solution diffusion method [39]. The content of extractable phosphorus (EP) was measured using the molybdenum-antimony anticolorimetric method (sodium bicarbonate extraction method) [40]. The extractable potassium (EK) was extracted with ammonium acetate and measured by flame photometry [41].

2.4. Statistical Analysis

All data were presented as the mean value of three replicates. Microsoft Excel 2019 was used for data processing and drawing. SPSS 18.0 software was used for one way analysis of variance (ANOVA) to test for significant differences. Comparisons among treatments were based on Duncan's multiple range test at the 0.05 probability level.

3. Results

3.1. Film Mulching Effects on Plant Growth

As can be seen from Table 2, in June 2019, film mulching treatment had significant effects on the number of plants per unit area. Compared with CK, the number of plants per unit area decreased by 67.7% and 66.3% when the coverage rates were 80% and 90%, respectively. In October 2019, compared with CK, the number of plants per unit area decreased by 53.7% and 58.8% when the coverage rates were 80% and 90%, respectively. In May 2020, the number of plants per unit area of each treatment decreased with the following order: CK > 40% > 50% > 60% > 70% > 80% > 90%. The number of plant per unit area with the coverage rate of 90% was reduced by 58% compared with CK (Figure 4).

Table 2. Plant growth and nutrients in the soil influenced by film mulching.

Parameter	Number of Plant Individuals per Unit Area	Plant Height (cm)	Plant Ground Diameter (cm)	Extractable N (mg kg^{-1})	Extractable P (mg kg^{-1})	Extractable K (mg kg^{-1})
June 2019						
F-value	693.32	89.88	94.88	88.33	429.90	184.90
p-value	0.00	0.00	0.00	0.00	0.00	0.00
October 2019						
F-value	111.15	101.04	1.96	-	615.94	248.87
p-value	0.00	0.00	0.14	-	0.00	0.00
May 2020						
F-value	452.89	165.65	-	-	337.03	187.43
p-value	0.00	0.00	-	-	0.00	0.00

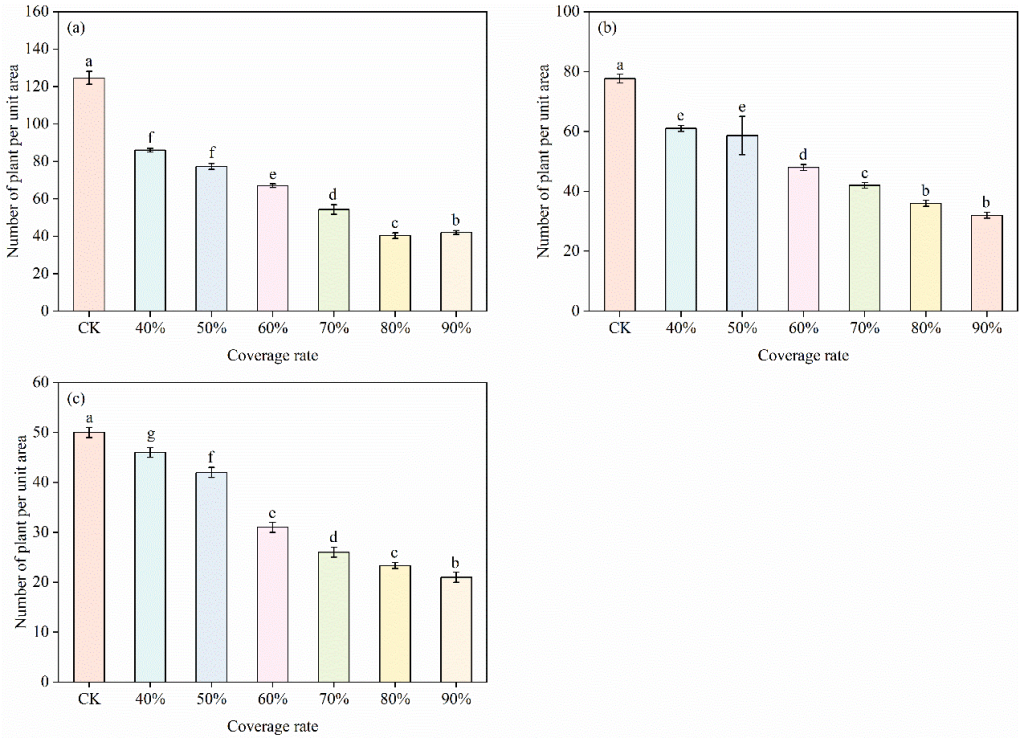

Figure 4. The effect of different coverage rates of film mulching on number of plants per unit area. (**a**) Data for June 2019, (**b**) data for October 2019, (**c**) data for May 2020. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

Within each observation period, the plant height after film mulching treatment was higher than that of CK (Figure 5), and the plant height of each treatment increased with the increase of coverage rate (i.e., CK < 40% < 50% < 60% < 70% < 80% < 90%). In June 2019, compared with CK, plant height increased by 90.5% when the coverage rate was 90%. In October 2019, the average plant height of each film mulching treatment was 26.3% higher than that of CK. In May 2020, the plant height under the condition of the 90% coverage rate increased by 46.6% compared with CK.

As can be seen from Figure 6, in October 2019, the plant biomass accumulation value of the film mulching treatment was higher than that of CK, and plant biomass increased by 44.4% when the coverage rate was 50%. In May 2020, there was no significant difference in plant biomass between treatments, with the average biomass of each film mulching treatment was only 2.2% higher than that of CK.

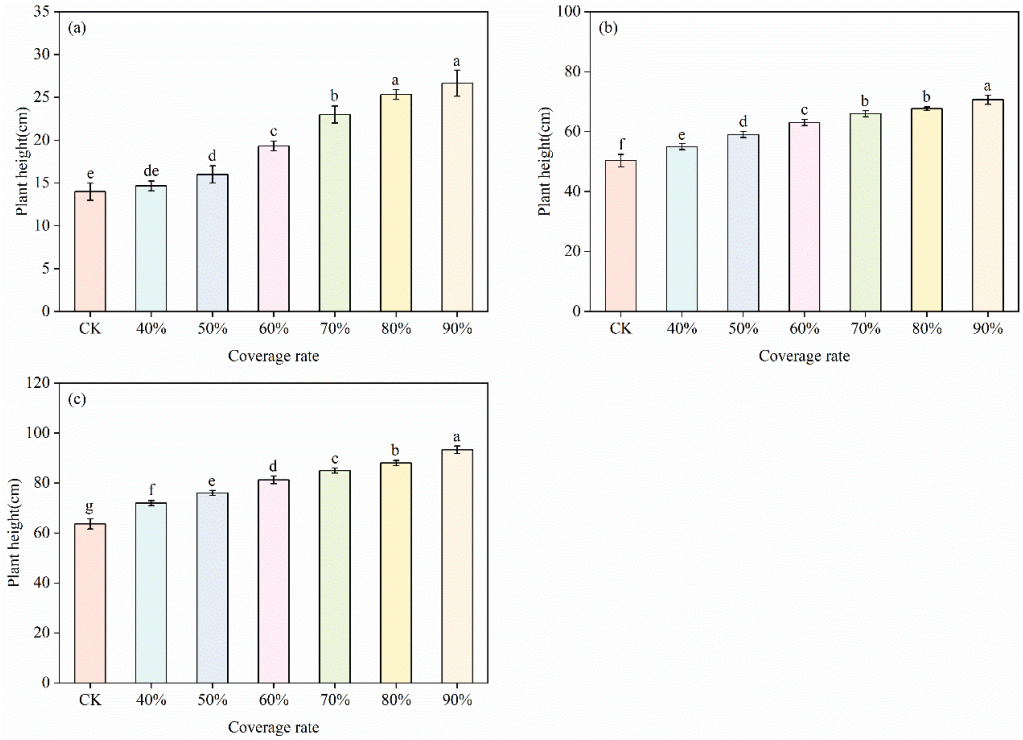

Figure 5. The effect of different coverage rates of film mulching on plant height. (**a**) Data for June 2019, (**b**) data for October 2019, (**c**) data for May 2020. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

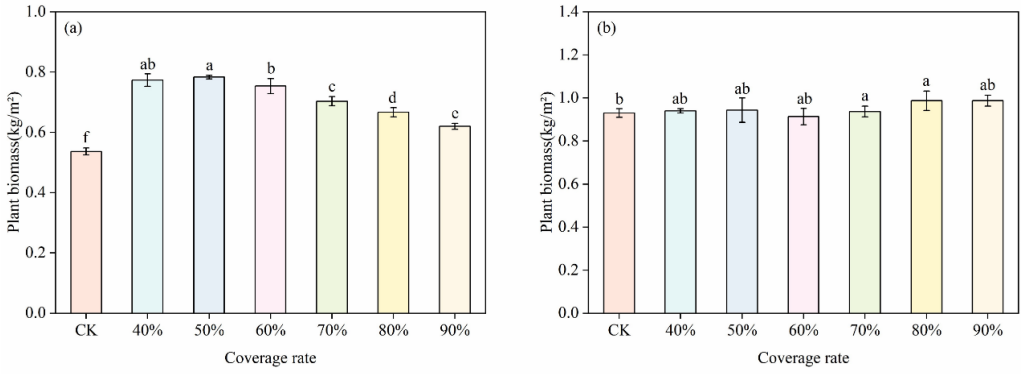

Figure 6. The effect of different coverage rates of film mulching on plant biomass. (**a**) Data for October 2019, (**b**) data for May 2020. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

Film mulching treatment had a significant impact on plant ground diameter (Table 2). In May 2020, the average ground diameter of each film mulching treatment was 40.4% higher than that of CK, and the ground diameter under the condition of 90% and 80% coverage rate increased by 64.3% and 54.9%, respectively (Figure 7).

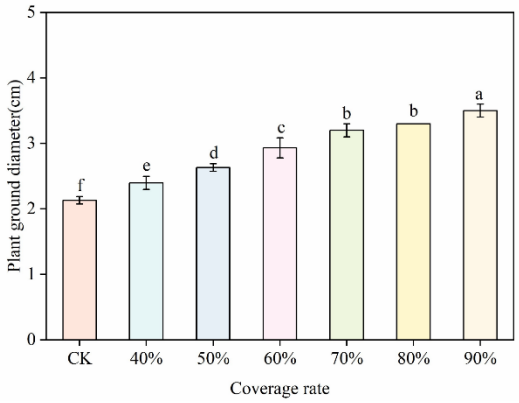

Figure 7. The effect of different coverage rates of film mulching on plant ground diameter. Data for May 2020. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

3.2. Film Mulching Effects on Nutrients in the Soil

Nutrient contents in the soil were significantly affected by film mulching treatment (Table 2). Within each observation period, the contents of EN, EP and EK in the soil of each treatment were decreased with the decrease in the coverage rate (i.e., 90% > 80% > 70% > 60% > 50% > 40% > CK). In June 2019, compared with CK, the contents of EN, EP and EK increased by 35.3%, 50.4% and 20.7%, respectively, with the coverage rate of 90%. In October 2019, compared with CK, the contents of EN, EP and EK increased by 44.5%, 45.3% and 28.1%, respectively, with the coverage rate of 90%. In May 2020, compared with CK, the contents of EN, EP and EK increased by 79.2%, 93.6% and 56.2%, respectively, under the 90% coverage rate (Figures 8–10).

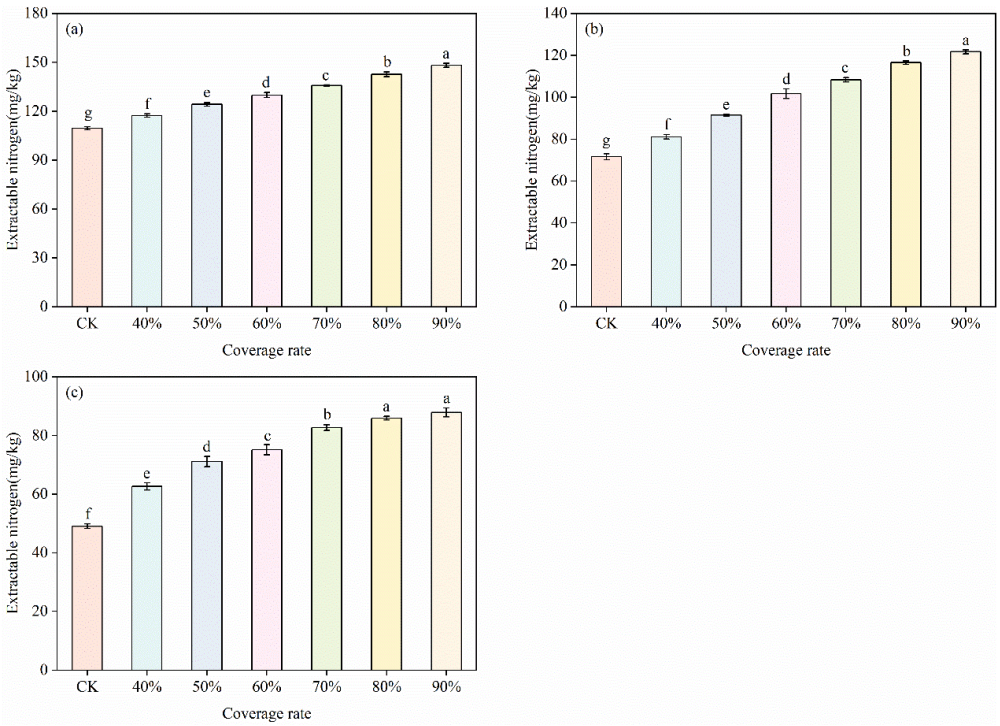

Figure 8. The effect of different coverage rates of film mulching on soil extractable nitrogen content. (**a**) Data for June 2019, (**b**) data for October 2019, (**c**) data for May 2020. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

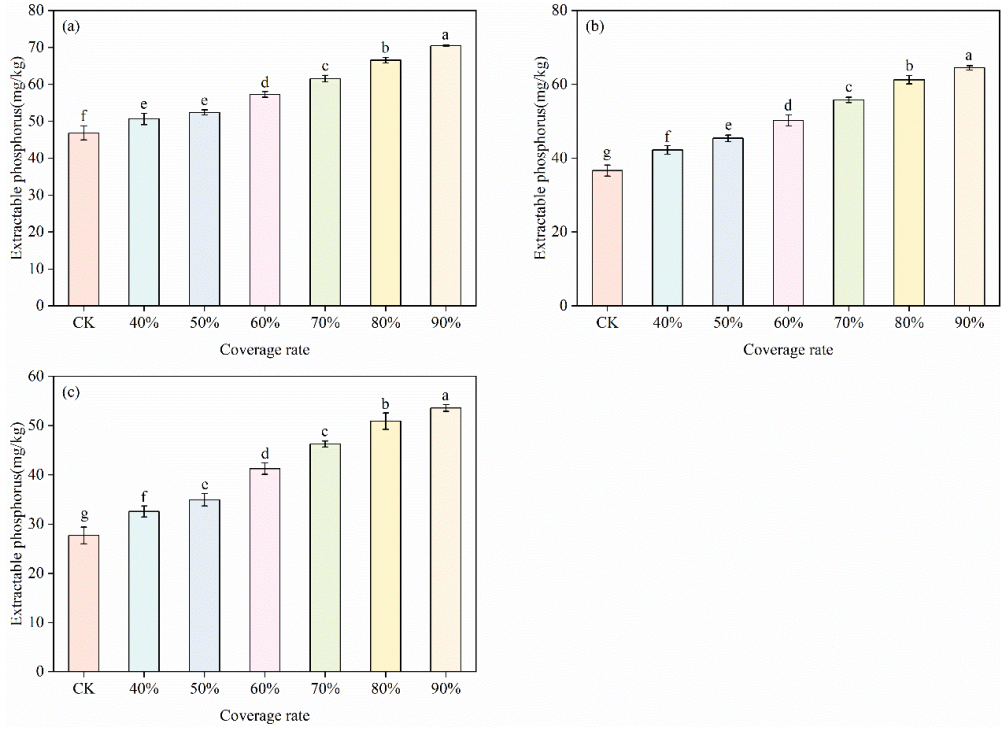

Figure 9. The effect of different coverage rates of film mulching on soil extractable phosphorus content. (**a**) Data for June 2019, (**b**) data for October 2019, (**c**) data for May 2020. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

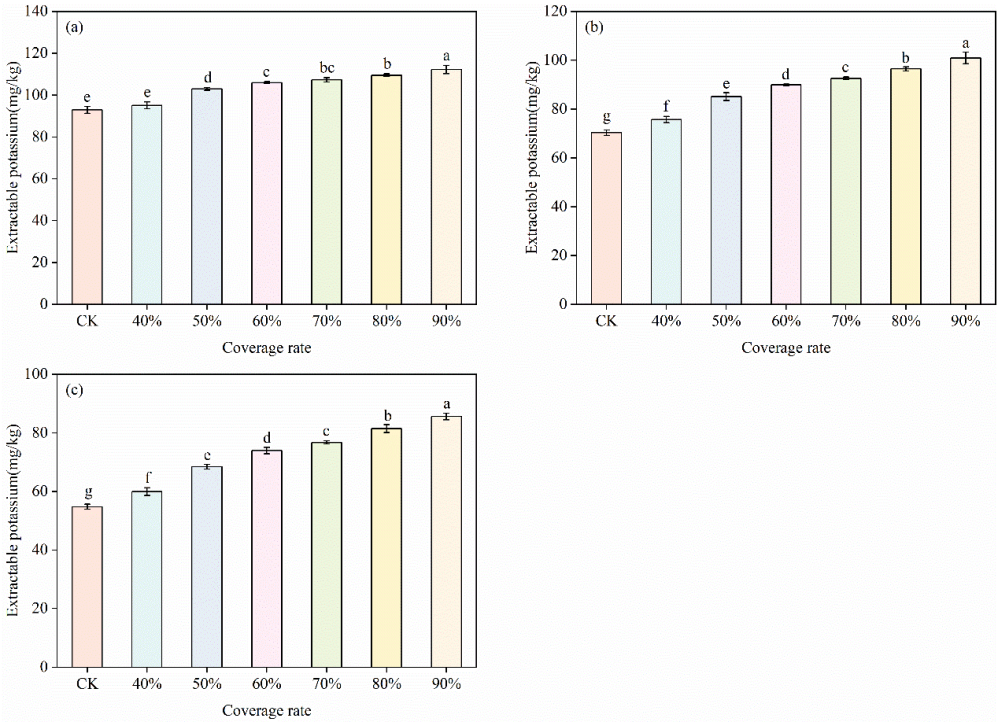

Figure 10. The effect of different coverage rates of film mulching on soil extractable potassium content. (**a**) Data for June 2019, (**b**) data for October 2019, (**c**) data for May 2020. Values with different letters indicate significant differences between treatments at $p < 0.05$. Vertical bars indicate standard errors of means.

4. Discussion

4.1. Film Mulching Effects on Plant Growth

4.1.1. Film Mulching and Number of Plant per Unit Area

Film mulching had both positive and negative effects on germination [42]. On one hand, film mulching can keep soil moisturized, preserve fertilizer and inhibit weed growth, which can significantly improve the survival rate of seedlings [43–45]. On the other hand, the existence of film also acts as a mechanical barrier, resulting in difficulties in the emergence of plants and reducing seedling survival rate [46]. Previous studies have shown that film mulching can promote seed germination and seedling development [47,48]. This indicates that the positive effects of soil temperature and moisture on plant emergence in the mulching area are greater than any adverse effects of mechanical impedance. In the initial vegetation recovery of slopes, vegetation showed good growth potential and covered the entire slope (Figure 11).



Figure 11. Distance view of ecologically restored slope.

In the early stages of the experiment (May 2019), the number of plants per unit area of the film mulching treatment was significantly lower than that of CK, and the higher the coverage rate was, the smaller the value was, indicating that the negative effect of film mulching on seed germination was more obvious. The film mulching was found to be completely degraded during the second survey conducted in October 2019. Compared with the initial stage of the experiment, the mortality of plants in the film mulching treatment was lower than that of CK, which could be because film mulching provided favorable conditions for the growth and development of plants.

4.1.2. Film Mulching and Plant Height

Plant height is the main index that determines plant growth. Some studies reported that there was a significant increase in plant height under the condition of film mulching [49,50]. Anikwe et al. (2007) observed that the plant height of taro in the black film covered area was 61–67% higher than that in the uncoated area [51]. This is consistent with our results. In this study, the plant height of the film mulching treatment was higher than that of CK in each observation period and the higher the coverage rate was, the higher the value was. The reason might be that the suitable water and heat conditions in the soil promoted the growth and development of plants [52]. It might also be that black mulch improved the light environment around the plants, reduced competition for light and, thus, affected plant growth [53].

4.1.3. Film Mulching and Plant Biomass

It has been suggested that the biomass of plants growing under film mulching is significantly higher [54,55]. Zhang et al. (2017) observed that film mulching significantly increased the biomass of maize, and the four-year average biomass was 75% higher than that of no film mulching [56]. The reason might be that the film mulching changes the water consumption pattern of plants during the growing period, thus promoting dry matter accumulation [57]. In addition, some studies have also reported a similar phenomenon of lower plant biomass under straw mulch [58]. This might be because the low temperature and relatively cool environment was not conducive to the accumulation of plant biomass. In our study, the biomass of the film mulching treatment was higher than that of CK, except for the observed data of the coverage rate of 60% (May 2020). The reason might be that film mulching improved soil moisture and heat conditions, thus accelerating plant growth under the film mulching treatment [59].

4.1.4. Film Mulching and Plant ground Diameter

Previous researchers have found that under the condition of film mulching, plants often show a significant increase in ground diameter [60–62], which was also observed in our study. Compared with CK, the ground diameter of the film mulching treatment was larger, and the higher the coverage rate was, the higher the value was. The reason might be that the higher soil temperature and water content improved the nutrient utilization rate of plants and the nutrient uptake by the root system, thus promoting the growth of plants [63,64]. It might also be that black mulch affected plant growth by changing insect behavior and reducing the number of pests [65].

4.2. Film Mulching Effects on Nutrients in the Soil

The availability of nutrients in the soil is closely related to the development and succession of plant communities, which also determines the growth rate, physiological vitality and species diversity of plants. Previous studies have suggested that the concentration of residual nutrients in the soil after mulching is higher, compared with nonmulching treatment [66–68]. This is likely because the high soil temperature and water content promoted the decomposition and transformation of organic matter in the soil [69]. However, some studies have also reported a lower concentration of soil residual nutrients under mulch [70]. Such differences might be attributed to the higher plant uptake rate with higher yield under mulching. It has been found that sweet corn yields under mulch were 40–50% higher than those recorded in plots without mulch (2017 and 2018) [71]. It might also be because the mulch film prevents rainfall infiltration, thus mitigating and even preventing runoff and soil erosion. Our results have showed that nutrients under measurement are mostly the ones that had been added during the recreation process. Thus, nutrients are not stabilized in soil in the form of absorbent complex linkage, suffering from leaching that is inversely proportionate with film covering ratio. As a result, increased runoff and soil erosion will reduce soil fertility [72,73].

In addition to the degradable film selected in this experiment, the covering materials commonly include straw, wood chips, gravel, and so on. Researchers found that, compared with uncovered areas, the contents of EN, EP and EK in the areas treated with the straw mulching and nitrogen fertilizer treatment increased by 28%, 45%, and 55%, respectively [74]. This is consistent with our research results. In this study, the contents of EN, EP and EK in the soil of each film mulching treatment were higher than those in CK in all observation periods, which might be due to the increase in soil moisture accelerating the migration and diffusion of nutrients [75]. In addition, the contents of EN, EP and EK in the soil were always the highest when the coverage rate was 90%. This might be because film mulching provided direct mechanical protection to the soil surface, reducing the direction contact of rainfall and, thus, nutrient losses due to leaching or surface runoff [76,77].

5. Conclusions

Vegetation restoration is not only beneficial to the stability of the slope but also can improve its surrounding environment. This study discussed the effects of film mulching on plant growth and nutrients in artificial soil on slopes. The results showed that the number of plants per unit area in the film mulching treatment was significantly lower than that of CK within each observation period, and the higher the coverage rate was, the smaller the value was (i.e., CK > 40% > 50% > 60% > 70% > 80% > 90%). The plant height, ground diameter, and the contents of EN, EP, and EK in the soil of the film mulching treatment were significantly higher than those of CK within each observation period, and the higher the coverage rate was, the higher the value was (i.e., CK < 40% < 50% < 60% < 70% < 80% < 90%). Film mulching provides a good growth environment for plants and increases the concentration of soil residual nutrients. To sum up, in combination with ecological and environmental protection, the application of degradable mulching film to slope vegetation restoration is a future development direction. Film mulching is an effective technique to prevent slope vegetation degradation, and successful vegetation restoration is also helpful to improve the natural aesthetics of the environment.

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