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Effect of *Gastrodia elata Bl* Cultivation under Forest Stands on Runoff, Erosion, and Nutrient Loss

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Abstract: (1) Background: The understory planting of Chinese herbal medicine is a common soil and water conservation farming measure, and this approach makes full use of the natural conditions of the understory. However, a large number of studies on soil erosion have focused on the simulation of natural indoor conditions, and there are very few investigations on soil erosion caused by understory planting in the field. This study aims to investigate the effects of different slopes on soil and water and nitrogen–phosphorus nutrient loss from understory planting of Gastrodia elata Bl by changing the vegetation structure and soil structure of forest land. (2) Methods: To reveal the nitrogen and phosphorus loss and flow and sediment characteristics of the understory planting of *Gastrodia elata Bl*, runoff plots were set up in a field, and three surface slopes (5°, 15°, and 20°) were designed to collect runoff sediments and compare the soil and water loss between the natural slopes and those with *Gastrodia elata Bl*. This provides a basis for the restoration of vegetation cover and the enhancement of soil fertility. (3) Results: The total loss of soil, water, nitrogen, and phosphorus in the forested land with *Gastrodia elata Bl* increased significantly compared with that in the natural forested land, and the greater the slope was, the greater the loss was. (4) Conclusions: Planting *Gastrodia elata Bl* should be avoided in areas with steep slopes and serious soil erosion. However, some soil and water conservation engineering measures can be taken, such as the construction of retaining walls, drainage ditches, etc., to minimize the scouring and erosion of soil by rainwater.

Keywords: understory planting; *Gastrodia elata Bl* plantation; runoff and sediment; nitrogen and phosphorus loss

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Citation: Yang, S.; Li, J. Effect of *Gastrodia elata Bl* Cultivation under Forest Stands on Runoff, Erosion, and Nutrient Loss. *Forests* **2024**, *15*, 1127. https://doi.org/10.3390/f15071127

Academic Editor: Reynaldo Campos Santana

Received: 8 May 2024
Revised: 20 June 2024
Accepted: 25 June 2024
Published: 28 June 2024

1. Introduction

Gastrodia elata Bl, as an important herb and ingredient, is favored for its unique pharmacological effects [1]. *Gastrodia elata Bl* is mainly artificially cultivated. Due to the increase in demand, more *Gastrodia elata Bl* is being cultivated [2]. At present, the most common planting methods are imitation wild and facility cultivation [3]. Wild cultivation is conducted under the forest canopy, simulating the original habitat of wild *Gastrodia elata Bl* [4]. The forest medicine model refers to the utilization of plant medicinal herbs cultivated and operated under the forest canopy. The advantage of growing *Gastrodia elata Bl* under the forest canopy is that it fully utilizes the space and resources and reduces the dependence on arable land [5], thus helping to protect other land resources [6]. At the same time, the understory planting of *Gastrodia elata* Bl can also increase soil fertility and improve the sustainable production capacity of land [7]. In recent years, the under-forest planting of *Gastrodia elata Bl* has gradually gained attention as a new planting mode [8]. However, the impact of this planting method on soil erosion has rarely been studied.

The understory planting of *Gastrodia elata Bl* may increase ground cover and provides a buffer for rainwater to land on the ground, thus reducing the risk of soil erosion. This is mainly because *Gastrodia elata Bl* needs to be covered with a layer of loose soil during its growth. This cover effectively reduces the impact of raindrops on the surface and the formation of surface runoff, inhibiting soil erosion. On the other hand, the understory cultivation of *Gastrodia elata Bl* may also exacerbate soil erosion. Since *Gastrodia elata Bl* cultivation requires regular loosening and weeding, this may lead to the destruction of ground cover and changes in the soil structure [9]. In 2015, there was 104,700 km^2 of soil erosion in Yunnan Province, accounting for 27.33% of the land area, and 481,430,000 t annual soil loss occurred. According to the ninth re-examination of the Yunnan Provincial Forest Resource Inventory, Yunnan Province has a total land area of 38,264,400 hm^2, of which 25,994,400 hm^2 is forested, with a coverage rate of 67.93%. In their "14th Five-Year" plan, Yunnan Province will improve the basic conditions of their 200,000 mu planting bases in some key counties (cities and districts) for the development of the region, totaling 300 acres [10]. However, the impact of forest planting *Gastrodia elata Bl on* soil erosion is complex.

Soil erosion is a worldwide environmental concern that can contribute to the degradation of soil structure and the loss of nutrients, ultimately resulting in diminished soil functionality and reduced crop yields [11]. The southern hilly regions are major agricultural production areas in China. The soil erosion in these regions is severe because of the thin soil, steep slopes, high temperatures, abundant rainfall, and high intensity of human reclamation [12,13]. In recent years, with the implementation of the national ecological civilization strategy, which aims to control soil erosion, soil nutrient loss has become an important research area for the agriculture and environmental sectors [14,15]. During production, the environmental conditions of the planting area, soil and water conservation measures' planting techniques, and other factors should be fully considered to ensure the development of the *Gastrodia elata Bl* industry and to effectively reduce its negative impact on the environment [16,17]. In recent decades, human activities have increased the availability of nutrients such as nitrogen (N) and phosphorus (P) in ecosystems [18,19]. It has been shown that increased runoff due to climate change over the next decade will be accompanied by increased losses of total nitrogen and phosphorus [20].

At present, research on soil erosion focuses on agricultural land, such as sloping croplands, and the influence of slopes, rainfall, and farming measures on soil erosion in sloping croplands has already formed a relatively perfect area of study. The previous research on soil erosion in forested land also mostly investigated the effect of different vegetation, vegetation cover, root growth, and other factors on soil and water retention, as well as the response of soil erosion and rainfall factors in the understory of forests. This study aims to investigate the effects of different slopes on soil and water and nitrogen-phosphorus nutrient loss from understory planting of *Gastrodia elata Bl* by changing the vegetation structure and soil structure of forest land. It can provide a theoretical reference for the sustainable development of forest land and data support for local forest fertilization management.

2. Materials and Methods

2.1. An Overview of the Study Area

The study area is located in Xiaodaohe Forest Farm (23.72°~23.89° N, 100.08°~100.11° E), Linxiang District, Lincang City, southwest Yunnan Province. The soil type is yellow loam. Xiaodaohe Forest Farm has a subtropical mountain monsoon climate, with an average annual precipitation total of 1400 mm, and 120 annual precipitation days on average, with a maximum of 130 and a minimum of 110. The extreme annual rainfall maximum is 1500 mm, and the extreme annual minimum rainfall is 1000 mm. Rainfall is concentrated from May to October each year, with July to August being the most rainy. As a result of severe soil erosion and human activities, the primary forests have been greatly reduced, and most of them have evolved into secondary vegetation warm-temperate coniferous and broad-leaved Yunnan pine forests, with a mosaic of various cross-distributed zonal vegetation, and the forest coverage rate is 80%. In early June 2023, weeds, small shrubs, and dead leaves were removed from planted areas. The sample plots were divided into three surveys, which are summarized in Table 1. The location of the district is shown in Figure 1.

Table 1. Basic characteristics of sample plots.

Sample Plot Number	Slope	Slope Direction	Typical Tree Species	Physical Characteristics	Diameter at Breast Height/cm	Tree Height/m	Shading
1—1	13°	South by west	Pinus yunnanensis	Forests that are nearly mature	23.92 ± 4.49	15.12 ± 1.5	70%
1—2	10°	South by west	Pinus yunnanensis	Forests that are nearly mature	23.85 ± 5.27	15.03 ± 1.77	70%
1—3	14°	South by west	Pinus yunnanensis	Forests that are nearly mature	25.45 ± 5.77	15.76 ± 1.68	65%

Note: Breast and tree height diameter data in the table are mean ± standard deviation.

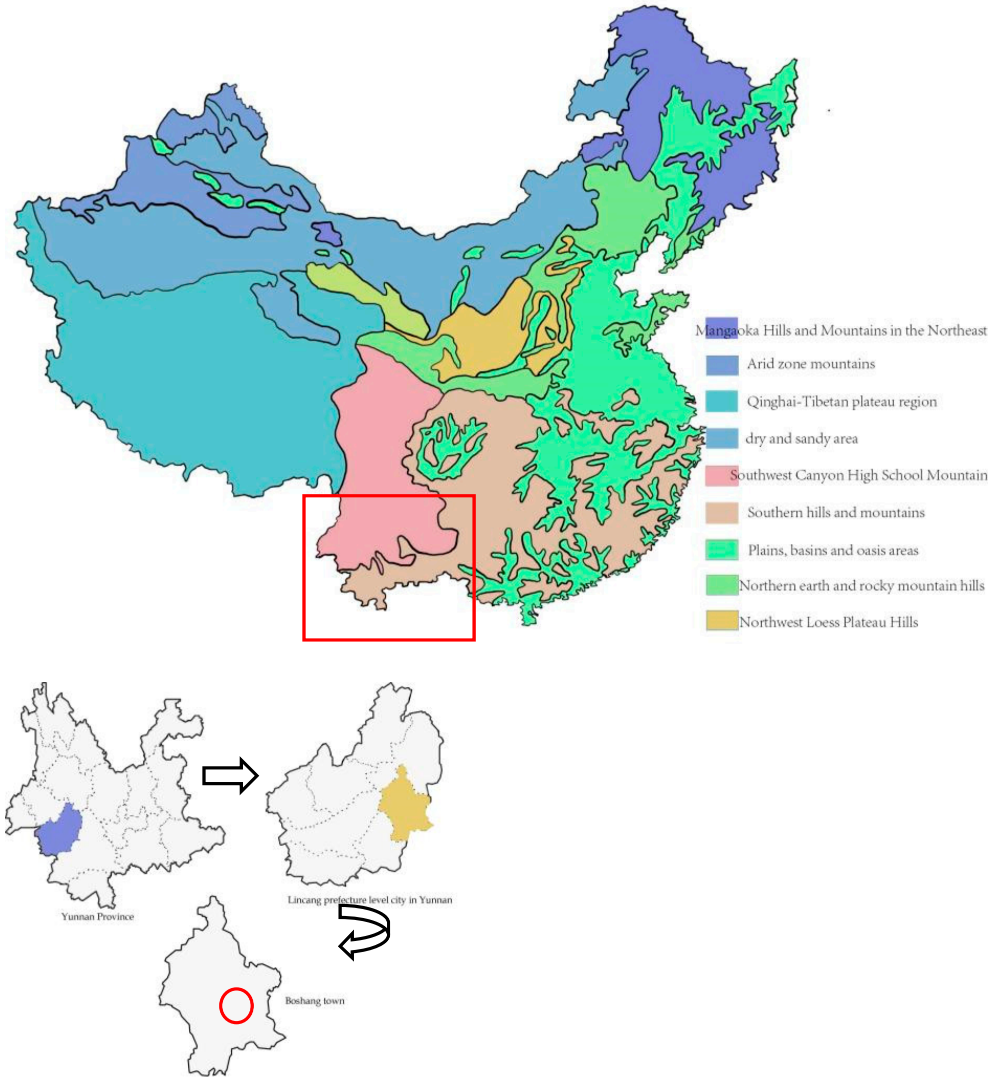

Figure 1. Soil and water erosion areas in the country of China which represent the study area.

2.2. Experimental Design

2.2.1. Design of Runoff Plots

During the cultivation of *Gastrodia elata Bl*, land preparation includes removing impurities, plowing, ridging, and setting up drainage ditches in the forest. One year after setting up the intensive seedling nursery outside the forest, *Gastrodia elata Bl* was transported to the understory planting base for transplanting after land preparation, with 10~15 cm × 10~15 cm between the plants and rows. The pine needles were mulched with a thickness of 2.5 cm after transplanting, which caused less disturbance. In addition, there was more withered material on the forest floor due to natural processes. Usually, *Gastrodia elata Bl* is cultivated under the forest canopy for 1 year [21].

In this experiment, six runoff plots (three runoff pools for *Gastrodia elata Bl* and three runoff pools for the natural sample plots) were constructed in the original landscape, with the *Gastrodia elata Bl* planting site in Boshang Town, Lincang City, as the sample site, and each plot was then laid out with an adjacent replicated plot as a control. The field runoff in situ experiment was used to observe soil, water, nitrogen, and phosphorus losses in the rainy season (June~September) of 2023 in the forested land (S) with *Gastrodia elata Bl*. The natural woodland with Yunnan pine (C), which was undisturbed and had relatively similar stand conditions to the forested land with *Gastrodia elata Bl*, was selected as the control. Three runoff plots with different slopes (5°, 15°, and 20°) were set up in each of the *Gastrodia elata Bl* and natural woodland sites, which are denoted as S5°, S15°, S20°, C5°, C15°, and C20°, respectively. The natural woodland runoff plots were 15 m × 5 m in size, and three paddling pools were laid out in each plot, connected to each other. In order to ensure the integrity of one drainage unit in the *Gastrodia elata Bl* woodland, it was 20 m × 15 m in size. The details are shown in Figure 2.

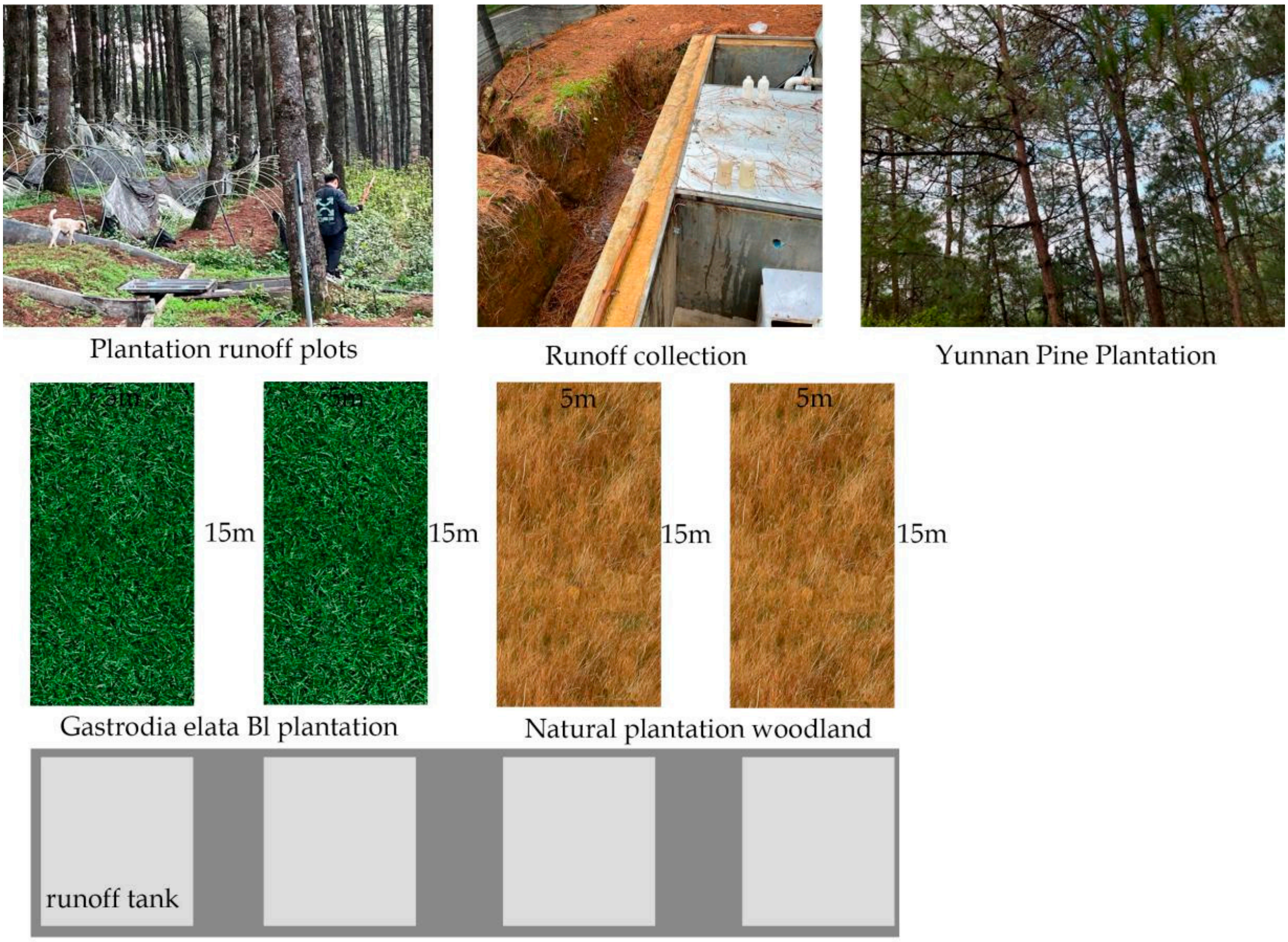

Figure 2. Sample and runoff plot settings.

2.2.2. Observation of Rainfall Indicators

A self-registering rain gauge (Onset HOBO RG3-M, USA) was set up near the runoff plots to observe the rainfall amount, duration, and 5-, 10-, and 30-min maximum intensities (I_5, I_{10}, and I_{30}, respectively) under the sub-rainfall conditions, and these characteristics are shown in Figures 3 and 4. A total of 655 mm of cumulative rainfall was recorded in the rainy season of 2023 (from June to September).

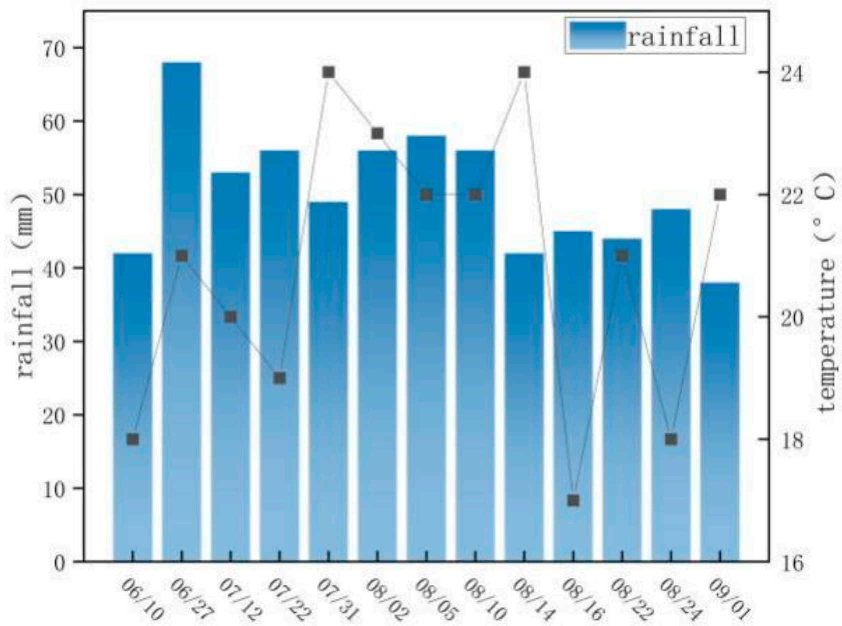

Figure 3. Rainfall and temperature changes in the study site.

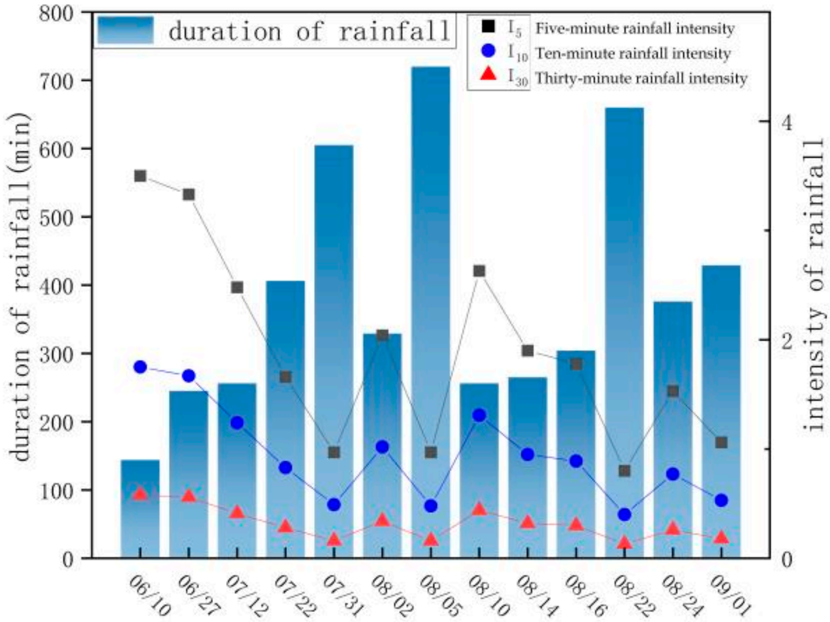

Figure 4. Rainfall duration and rainfall intensity.

2.2.3. Runoff Sediment Collection

After the start of the 2023 rainy season, 13 experimental samples were collected for runoff and erosion sediment determination. The water level in the pool of the runoff plot was measured (to an accuracy of 0.1 cm) to calculate the flow rate of production; water samples were collected using the stirring method by taking a bottle of un-stirred water samples. After this, a bottle of water–sediment mixture samples were collected by completely stirring up the sediment in the runoff pool, and then the erosion samples were collected using a filter bag after the sediment in the pool had settled down. The filter bag was placed in a cool place to dry naturally, and the pine needles and other debris were picked out. This was sealed and labeled for subsequent measurement [22].

2.2.4. Nutrient Loss Measurement Experiment

The nutrient losses due to surface runoff and eroded sediments were analyzed by looking at the physical and chemical properties of the soil. The collected rainwater samples were filtered before measurement using a machine. The collected soil samples were naturally dried, sieved, and placed in self-sealing bags for routine soil analysis [23]. The collected rainwater samples were filtered through a 0.45 µm membrane and loaded into 50 mL centrifuge tubes to be measured, after which the total nitrogen (TN), total phosphorus (TP), nitrate nitrogen (NO_3^--N), and ammonium nitrogen (NH_4^+-N) were determined using a continuous flow analyzer; 0.1 g of air-dried sediment was dissolved in concentrated sulfuric acid peroxide and then used to determine the total nitrogen (TN) and total phosphorus (TP) contents using a continuous flow analyzer.

2.3. Data Processing

Excel and SPSS27.0 software were used to process and analyze the data, which mainly included the description of basic indexes, the use of pairwise statistical comparisons, multiple comparisons (Duncan's test) between each cultivation plot and their respective natural control plots to test the differences between the *Gastrodia elata Bl* and natural woodland, and Pearson correlation analysis to analyze the relationship between the rainfall characteristics and soil and water nutrient losses. The data are expressed as "mean ± standard deviation". The results conformed to a normal distribution, and the correlation plots of the experimental results were plotted using Origin2021.

3. Results

3.1. Characteristics of Runoff Sands on Forested Land during Gastrodia elata Bl Cultivation

The differences in flow and soil losses between the planted and natural forests with *Gastrodia elata Bl* under sub-rainfall conditions were significant ($p < 0.05$), with the average flow and soil losses ranging from 0.75 to 1.11 mm and 0.04 to 0.25 t/km^2, respectively.

As shown in Table 2, on the same slope, the total runoff and soil losses with *Gastrodia elata Bl* were significantly higher than those of the natural forested land, and they increased with the increase in the slope. The total runoff and soil losses were highest at S_{20°, with 2.9 mm and 1.24 (t·km^2), respectively, followed by S_{15°, with 2.5 mm and 0.54 (t·km^2), respectively. S_{5° had the smallest values, with 2.1 mm and 0.27 (t·km^2), respectively. The average total runoff and soil losses of the different slopes were 25.4 mm and 4.04 (t·km^2), which were 25.6% and 204.8% higher than those of the natural forest.

Table 2. Characteristics of flow production and sediment in forested and natural forested areas with different slopes of *Gastrodia elata Bl* under sub-rainfall conditions.

Treatment	Runoff/mm			Soil Loss/(t·km^2)		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
S_{5°	2.10	0.25	0.94 ± 0.54 a	0.27	0.01	0.08 ± 0.06 b
C_{5°	1.7	0.20	0.75 ± 0.47 a	0.11	0.01	0.04 ± 0.23 b
S_{15°	2.50	0.30	1.02 ± 0.55 a	0.54	0.03	0.27 ± 0.35 a
C_{15°	2.0	0.30	1.06 ± 0.63 a	0.11	0.02	0.05 ± 0.25 b
S_{20°	2.9	0.10	0.8 ± 0.68 a	1.24	0.01	0.11 ± 0.11 b
C_{20°	2.42	0.20	1.11 ± 0.76 a	0.1	0.01	0.05 ± 0.24 b

Note: graphs are mean ± standard deviation, different letters represent significant differences.

As shown in Figure 5, the amount of sediment in the forested land with *Gastrodia elata Bl* was significantly higher than that in the natural forest, and the amount of sediment in the forested land with *Gastrodia elata Bl* was the greatest when the slope gradient was S_{20°. The graph shows the mean rainfall and sediment yield and the standard deviation.

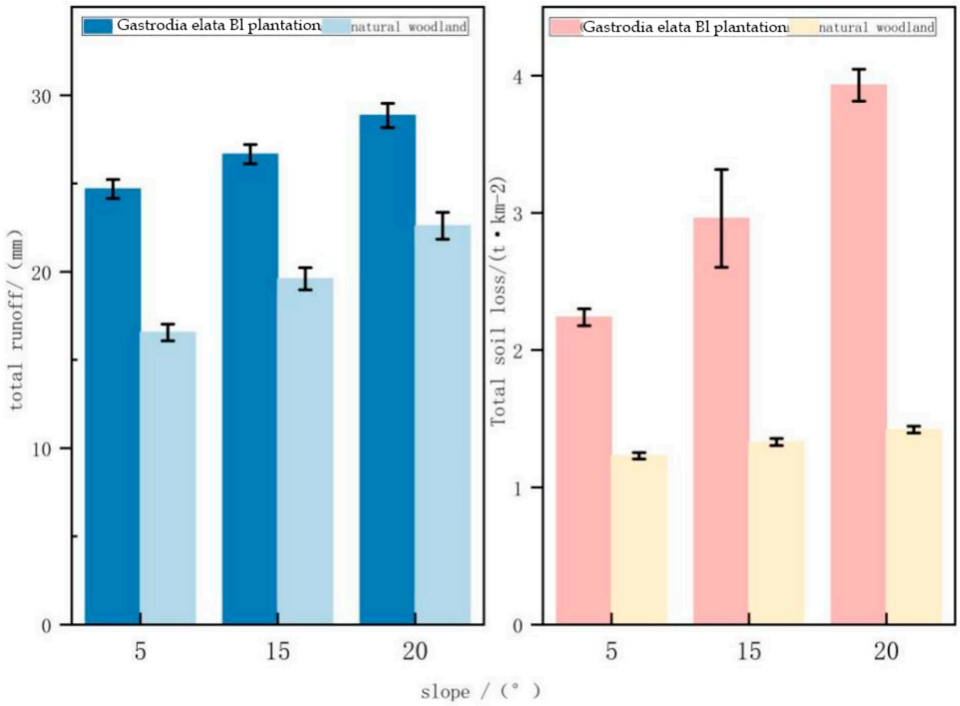

Figure 5. Total runoff and total soil loss from *Gastrodia elata Bl* plantation woodland with different slopes.

3.2. Effect of Different Slopes on Runoff Nutrient Loss of Gastrodia elata Bl Planted under Forest Canopy

As shown in Table 3, the mean total nitrogen contents in the runoff of the forest with *Gastrodia elata Bl* and natural forest were 1.15~1.67 mg/L and 0.89~1.29 mg/L, and that in the forest with *Gastrodia elata Bl* was 40% higher than that in the natural forest when the slope was 20°. The total phosphorus contents in the runoff of the forest with *Gastrodia elata Bl* and the natural forest were 0.05~0.08 mg/L and 0.03~0.05 mg/L; the smaller the slope was, the higher the whole phosphorus content was in the *Gastrodia elata Bl* woodland compared to that of the natural woodland. The whole phosphorus content of the *Gastrodia elata Bl* woodland was higher than that of the natural woodland by 166.7%, 40%, and 25% at the slopes of S_{5°, S_{15°, and S_{20°.

Table 3. Total nitrogen and phosphorus contents of *Gastrodia elata Bl* and natural woodland during runoff.

Treatment	TN/(mg/L) TN in Runoff			TP/(mg/L) TP in Runoff		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
S_{5°	4.29	0.23	1.67 ± 0.98 a	0.08	0.01	0.03 ± 0.02 a
C_{5°	4.73	0.18	1.29 ± 1.01 b	0.03	0.01	0.01 ± 0.01 b
S_{15°	3.26	0.10	1.21 ± 0.67 bc	0.07	0.01	0.01 ± 0.011 b
C_{15°	4.39	0.27	1.13 ± 0.85 bc	0.05	0.01	0.02 ± 0.01 b
S_{20°	2.96	0.16	1.15 ± 0.65 bc	0.05	0.01	0.011 ± 0.01 b
C_{20°	2.10	0.12	0.89 ± 0.51 c	0.04	0.01	0.013 ± 0.01 b

Note: graphs are mean ± standard deviation, different letters represent significant differences.

As can be seen in Figure 6, the average TN content of the forest with *Gastrodia elata Bl* before the rainy season was from 40% to 76% lower than that of the natural forest. The TN content of the forest with *Gastrodia elata Bl* was higher than that of the natural forest after fertilization; in addition, the average TP content of the forest with *Gastrodia elata Bl* before the rainy season was 80% to 500% higher than that of the natural forest. The TN and TP contents in the runoff increased after fertilizers were applied on 16 August, and they were more prevalent in runoff when rainfall was heavier.

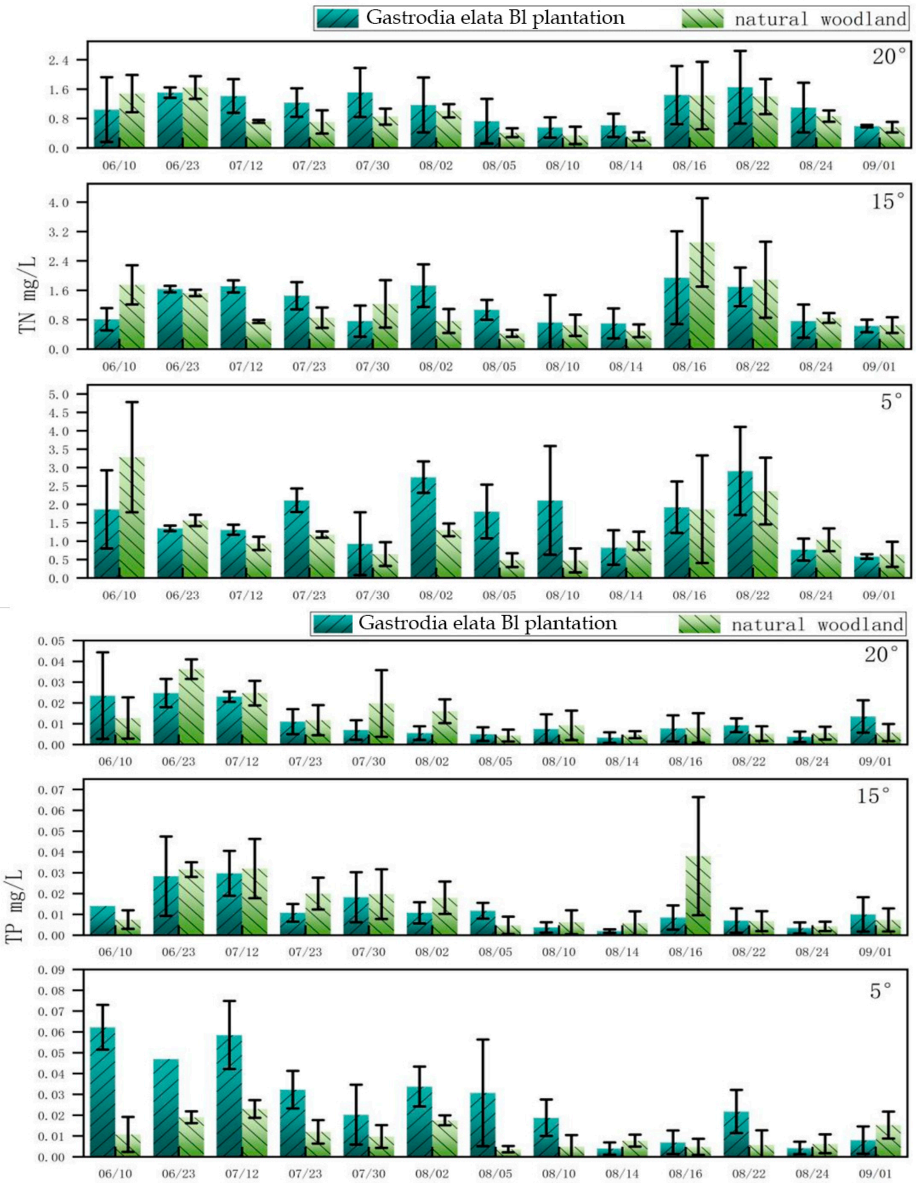

Figure 6. Changes in TN and TP content in runoff from *Gastrodia elata Bl* and natural forests with different slopes during the rainy season.

As can be seen from Table 4, the NO_3^--N contents in the runoff from the *Gastrodia elata Bl* and natural woodlands ranged from 0.35 to 0.58 mg/L and from 0.17 to 0.3 mg/L. On the same slope, there was significantly more NO_3^--N in the *Gastrodia elata Bl* woodland than that in the natural woodland; at the slopes of $S_{5°}$, $S_{15°}$, and $S_{20°}$, the NO_3^--N content was 93%, 45.8%, and 141.1% higher than that of the natural woodland. The NH_4^+-N contents in the runoff from the *Gastrodia elata Bl* and natural woodlands ranged from 0.35 to 0.37 mg/L and from 0.34 to 0.35 mg/L. On the same slope, the NH_4^+-N content in the *Gastrodia elata Bl* woodland was slightly higher than that in the natural woodland; however, at the slopes of $S_{5°}$, $S_{15°}$, and $S_{20°}$, the NH_4^+-N content was higher than that of the natural woodland by 2.94%, 5.89%, and 5.71%.

As can be seen in Figure 7, the NO_3^--N and NH_4^+-N contents of the natural forest were higher than those of the forest with *Gastrodia elata Bl* before the rainy season, and there was more in the runoff of the forest with *Gastrodia elata Bl* than there was in the natural forest after the beginning of the rainy season. The greater the slope was, the higher the NO_3^--N and NH_4^+-N losses were, which eventually enriched the gently sloping land.

Table 4. Nitrate nitrogen and ammonia nitrogen in runoff from *Gastrodia elata Bl* and natural woodlands.

Treatment	NO_3^--N mg/L in Runoff			NH_4^+-N mg/L in Runoff		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
$S_{5°}$	2.56	0.01	0.58 ± 0.66 a	1.27	0.06	0.35 ± 0.24 a
$C_{5°}$	1.55	0.06	0.3 ± 0.26 bc	1.11	0.06	0.34 ± 0.21 a
$S_{15°}$	1.16	0.06	0.35 ± 0.29 b	1.35	0.06	0.36 ± 0.27 a
$C_{15°}$	2.02	0.05	0.24 ± 0.27 cd	1.38	0.06	0.34 ± 0.23 a
$S_{20°}$	1.49	0.07	0.41 ± 0.32 bc	1.41	0.06	0.37 ± 0.27 a
$C_{20°}$	0.5	0.06	0.17 ± 0.09 d	1.29	0.06	0.35 ± 0.26 a

Note: graphs are mean ± standard deviation, different letters represent significant differences.

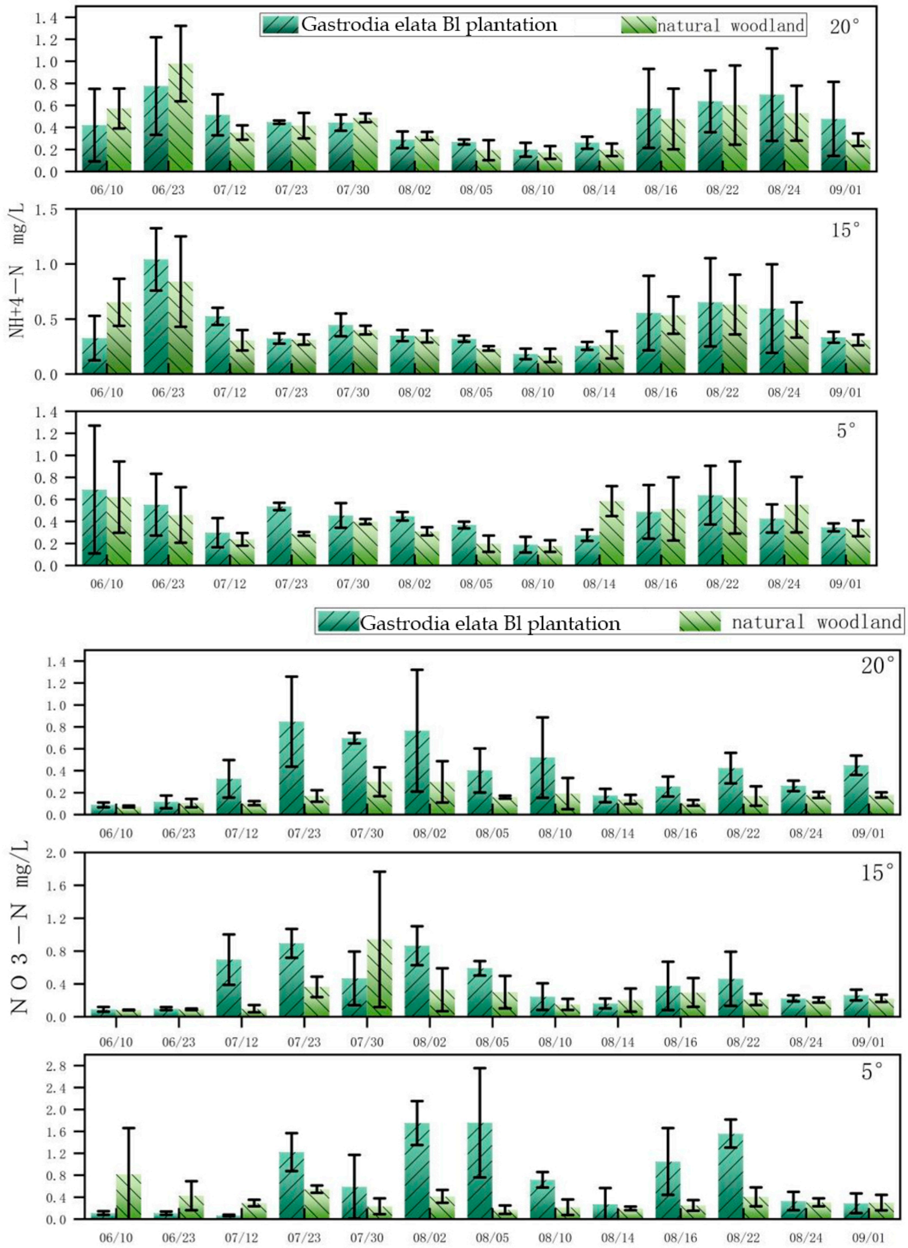

Figure 7. Changes in NO_3^--N and NH_4^+-N content in runoff from *Gastrodia elata Bl* plantations and natural forests with different slopes in the rainy season.

3.3. Effect of Different Slopes on Sediment Nutrient Loss of Gastrodia elata Bl in Forest Plantations

From Table 5 and Figure 8, the TN contents in the sediments of the forest with *Gastrodia elata Bl* and the natural forest ranged from 7.38 to 7.89 mg/L and from 8.10 to 14.79 mg/L. On the same slope, there was significantly more TN in the sediments of the natural forest than there was in the forest with *Gastrodia elata Bl*; at the slopes of $S_{5°}$, $S_{15°}$, and $S_{20°}$, the TN content of the natural forest was higher than that of the forest with *Gastrodia elata Bl* by 87.4%, 50.98%, and 9.76%, respectively. The TP contents in the sediments of the *Gastrodia elata Bl* forest and the natural forest ranged from 1.45 to 1.57 mg/L and from 1.08 to 2.07 mg/L. The TP content of the natural forest was higher than that of the *Gastrodia elata Bl* forest by 31.84% and 4.51% at the slopes of $S_{5°}$ and $S_{15°}$, and it was 34.25% at $S_{20°}$.

Table 5. Total nitrogen and phosphorus content of *Gastrodia elata Bl* plantation and natural woodland in sediments.

Treatment	TN/(mg·L^{-1}) TN in Sediment			TP/(mg·L^{-1}) TP in Sediment		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
$S_{5°}$	13.41	2.69	7.89 ± 2.62 c	2.76	0.56	1.57 ± 0.51 b
$C_{5°}$	21.06	4.58	14.79 ± 4.78 a	2.85	0.58	2.07 ± 0.71 a
$S_{15°}$	14.66	3.19	7.69 ± 2.38 c	3.08	0.76	1.55 ± 0.46 b
$C_{15°}$	21.73	2.46	11.61 ± 5.08 b	2.68	0.35	1.62 ± 0.62 b
$S_{20°}$	13.79	1.60	7.38 ± 2.45 c	2.33	0.06	1.45 ± 0.54 b
$C_{20°}$	15.06	3.35	8.10 ± 3.36 c	1.65	0.62	1.08 ± 0.31 c

Labeling: graphs are mean ± standard deviation, different letters represent significant differences.

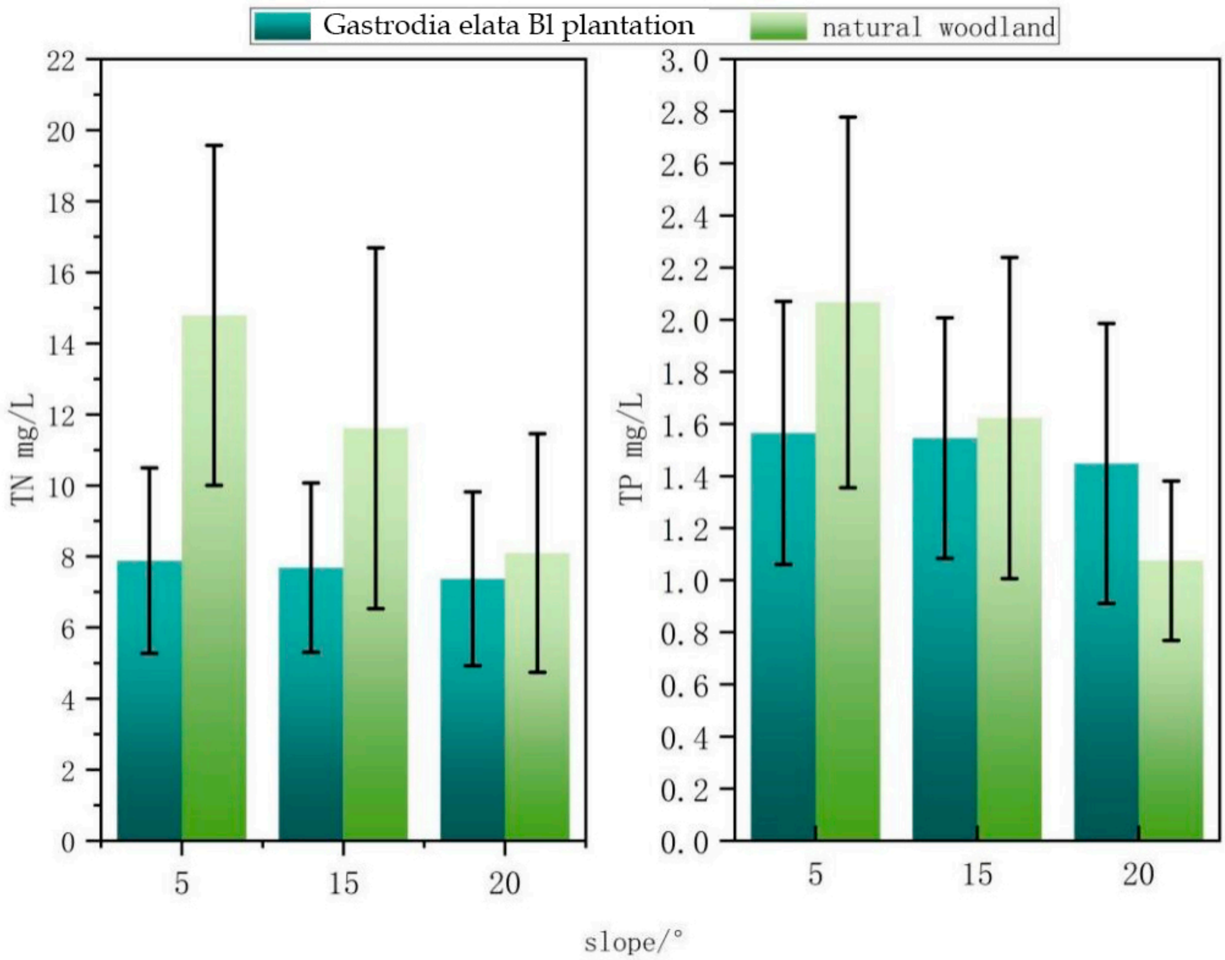

Figure 8. Total nitrogen and total phosphorus in sediments of different slopes.

3.4. Relationship between Runoff and Nutrient Loss from Sediments in Gastrodia elata Bl Plantation Stands

As can be seen from Table 6, the runoff volume was positively correlated with TP loss in the runoff (0.172, $p < 0.05$). Soil loss was positively correlated with NO_3^--N loss in the runoff (0.169, $p < 0.05$). TN loss in the runoff was positively correlated with TP,

NO_3^--N, and NH_4^+-N losses in the runoff, respectively, with highly significant positive correlations, respectively (0.33, $p < 0.01$; 0.248, $p < 0.01$; 0.263, $p < 0.01$). TP loss in the runoff showed a significant correlation with the runoff volume (0.172, $p < 0.05$), and there were highly significant positive correlations with the losses of TN and NH_4^+-N in the runoff, respectively (0.339, $p < 0.01$; 0.214, $p < 0.01$; 0.339, $p < 0.01$; 0.215, $p < 0.01$; 0.215, $p < 0.01$; 0.339, $p < 0.01$; 0.214, $p < 0.01$). TP loss in the sediments showed a significant negative correlation with the runoff volume and NH_4^+-N loss in the runoff, respectively (−0.34, $p < 0.01$; −1.87, $p < 0.05$), and a significant positive correlation with TN loss in the sediments and NO_3^--N loss in the runoff (0.813, $p < 0.01$; 0.173, $p < 0.05$). NO_3^--N loss in the runoff showed a significant positive correlation with soil loss and TN loss in the runoff, respectively (0.169, $p < 0.05$; 0.248, $p < 0.01$). NH_4^+-N loss in the runoff showed a highly significant positive relationship with TN and TP losses in the runoff (0.263, $p < 0.01$; 0.214, $p < 0.01$). TN loss in the sediments showed a significant negative correlation with the runoff volume and NH_4^+-N loss in the runoff, respectively (−0.23, $p < 0.01$; −0.184, $p < 0.05$).

Table 6. Correlation analysis between *Gastrodia elata Bl* runoff and nutrient loss from sediments.

	Runoff Volume	Soil Loss	TN Loss in Runoff	TP Loss in Runoff	TN Loss from Sediment	TP Loss in Sediment	NO_3^--N Loss in Runoff	NH_4^+-N Loss in Runoff
Runoff volume	1							
Soil loss	−0.084	1						
TN loss in runoff	−0.012	−0.06	1					
TP loss in runoff	0.172 *	−0.06	0.339 **	1				
TN loss from sediment	−0.239 **	−0.074	−0.088	−0.11	1			
TP loss in sediment	−0.340 **	0.067	0.015	−0.13	0.813 **	1		
NO_3^--N loss in runoff	−0.067	0.169 *	0.248 **	0.002	0.015	0.173 *	1	
NH_4^+-N loss in runoff	0.129	−0.084	0.263 **	0.214 **	−0.184 *	−0.187 *	−0.026	1

Note: Data in the same column followed by * indicate significant differences between treatments ($p < 0.05$), and ** indicates highly significant differences between treatments ($p < 0.01$).

4. Discussion

4.1. Impact of Forest Gastrodia elata Bl Planting on Soil and Water and Nitrogen and Phosphorus Nutrient Losses

Soil nutrients are provided by the soil during plant growth, which is an important factor in evaluating the natural fertility of soil [24]. Plants need all kinds of nutrient elements during growth, of which nitrogen (nitrogen, N) and phosphorus (phosphorus, P) are important for the maintenance of cellulose and energy systems in their bodies. The soil nutrient content also measures soil fertility, which plays an important role in the growth and development of plants [25,26]. The results of this study show that the average losses of TN and TP in the forest with *Gastrodia elata Bl* are 25.4 mm/a and 4.04 t/km^2, which represent 25.6% and 204.8% more than those of the natural forest, respectively, so it can be seen that the planting of *Gastrodia elata Bl* has a significant impact on soil and water erosion in forest land. On the other hand, the significant increase in soil erosion in the forest with *Gastrodia elata Bl* is due to the fact that vegetation and dead leaves under the forest canopy were cleared during the land preparation process, which resulted in the loss of the hydrological-ecological effect in the understory vegetation and dead leaf layers [27]. However, land preparation resulted in the destruction of the soil structure, so the soil's resistance to erosion was weakened. On the 20° slope in the forested land with *Gastrodia elata Bl*, more soil was lost (1.24 t/km^2); this value is lower than the permissible soil loss in the southwestern soil and rocky mountainous areas (500 t/km^2). The intensity was due to slight erosion [28]. This is because although understory *Gastrodia elata Bl* planting had a negative impact on soil erosion, contour furrow ridging itself is a soil and water conservation measure, together with the cover provided by Yunnan pine needles on the ridges, thereby reducing soil erosion to a certain extent [29].

Surface runoff and eroded sediment are the main causes of nutrient loss on slopes, and the process of nutrient loss on slopes is an interaction between the surface soil nutrients, rainfall, runoff, and sediments [30]. This study showed that the total nitrogen contents in the runoff of the *Gastrodia elata Bl* and natural woodlands ranged from 1.15 to 1.67 mg/L and from 0.89 to 1.29 mg/L. The total phosphorus content in the runoff of the *Gastrodia elata Bl* and natural woodlands ranged from 0.05 to 0.08 mg/L and from 0.03 to 0.05 mg/L. The total phosphorus contents of the *Gastrodia elata Bl* woodland were 166.7%, 40%, and 25% higher than those of the natural woodland at the slopes of 5°, 15°, and 20°. It can be seen that the nitrogen and phosphorus contents of the forest with *Gastrodia elata Bl* were higher than those of the natural forested land, which may be due to the application of an organic fertilizer before planting *Gastrodia elata Bl*, so more nutrient loss occurred. In addition, the average contents of TN and NH_4^+-N in the runoff from the forested land with *Gastrodia elata Bl* were 0.35–0.58 mg/L and 0.35–0.37 mg/L, which are lower than the environmental quality standards for surface water of Classes III and II, respectively [31].

4.2. Effects of Rainfall Characteristics and Slopes on Soil, Nitrogen, and Phosphorus Nutrient Losses

Rainfall and its intensity are the main factors determining its erosive power and runoff volume. The way vegetation regulates soil erosion has been understudied in southern low-altitude hilly areas; however, short, heavy rainfall events have occurred frequently in these regions in recent years, and the amount of soil erosion caused by a single heavy rainfall event may reach 60% for the whole year. With increased rainfall volume and more intense surface runoff, which represent stronger erosive and transporting force [32], more soil and nutrients from slopes are lost. During heavy rainfall ($\geq$50 mm$\cdot h^{-1}$), nutrient loss occurs mainly through surface runoff. In this study, more TN and TP in the soil was lost with increased rainfall intensity, which is similar to the result of a previous study [33], and the total phosphorus mass concentration had a tendency to first increase and then decrease from the early to the late stages of rainfall, mainly because the sampling of runoff basically followed rainfall. This reflects a gradual increase in total phosphorus loss in the runoff at the early stage of rainfall, as well as a gradual decrease in total phosphorus content in the late stage, with receding runoff. The total phosphorus content in the runoff also reduced in the later stages of rainfall recession. Nitrogen in runoff water mainly exists as water-soluble nitrogen [34], and more NO_3^--N than NH_4^+-N was lost in the *Gastrodia elata Bl* woodland, while the opposite was true in the natural woodland [35,36]. The runoff sand content is an important parameter for evaluating the degree of soil erosion, and it can characterize the growth and evolution of the water–sand relationship on slopes [37]. In this experiment, sampling was carried out for 4 months, and rainfall mainly occurred between July and August. This rainfall experiment was carried out to study the effect of different slopes on the loss of nutrients from the ground surface, and the conclusions obtained show that the nutrient concentration in the runoff and the loss of nutrients in the sediments decreased with the increase in the slope gradient. More total nitrogen than total phosphorus was lost [38]. In this study, by collecting and analyzing natural rainfall, the slope runoff volume, and the runoff sediment content in 12 artificial runoff plots and comparing the natural woodland forest downslope runoff and sediment yield, it was concluded that the runoff volume, soil loss, and nitrogen and phosphorus losses of the *Gastrodia elata Bl* and natural woodlands all increased with the increase in slope gradient. This is because as the slope increases, more soil and nutrients are lost. And from the results of this study, it is clear that the cultivation of *Gastrodia elata Bl* not only exacerbates soil erosion and the loss of soil nutrients but also alters the balance of nutrients in the soil and has an impact on the natural plant community. Therefore, the planting of *Gastrodia elata Bl* should be avoided in areas with steep slopes and serious soil erosion, and some soil and water conservation engineering measures should be taken [39], such as the construction of retaining walls and drainage ditches, in order to minimize the scouring of soil and erosion by rainwater.

5. Conclusions

July and August are the concentrated period of local rainfall, and based on rainfall amount, rainfall duration, and rainfall intensity, rainfall in the study area can be categorized into type A (small rainfall, short duration, and low rainfall intensity), type B (large rainfall, long duration, and medium rainfall intensity), and type C (medium rainfall, medium duration, and high rainfall intensity). The highest frequency of occurrence in this study area is type A. Rainfall types B and C are the main types of rainfall that produce flow and sand on slopes.

Under the same slope, the soil erosion of *Gastrodia elata Bl* planting was significantly higher than that of natural woodland. Compared with the natural woodland, the total runoff and total soil loss of the forested land planted with *Gastrodia elata Bl* increased by 25.6% and 204.8%, respectively. The soil loss of forested land planted with *Gastrodia elata Bl* was much lower than the permissible soil loss 500 (t/km^2) in the Southwest Barrow Mountain, and the intensity of soil erosion was slight.

At the same slope, the nitrogen and phosphorus loss in the forest land planted with *Gastrodia elata Bl* was significantly higher than that in the natural forest land. Rainfall and soil erosion were the main pathways for TN and TP loss, while surface runoff was the main pathway for NH_4^+-N and NO_3^--N loss. The average contents of NH_4^+-N and NO_3^--N in the runoff from the forested land planted with *Gastrodia elata Bl* were lower than the limit values of the environmental quality standards for Classes III and II surface water, respectively.

Author Contributions: Conceptualization, J.L. Methodology: description of basic indexes; multiple comparisons (Duncan's test); Pearson correlation analysis; software—SPSS, Origin, Photoshop, and Excel. Validation, J.L. Formal analysis, S.Y. Investigation, S.Y. Experimental preparation, S.Y., Data curation, S.Y. Writing—original draft preparation, S.Y. Writing—review and editing, S.Y. Visualization, S.Y. Supervision, J.L. Project administration, J.L. Funding acquisition, J.L. All authors have read and agreed to the published version of the manuscript.

Funding: The Kunming Science and Technology "List of Commanders" Project "Ecological Assessment System and Platform Construction of Forest Organic *Panax pseudoginseng*" (2021-J-H-002-02); the Yunnan Provincial Science and Technology Major Special Program "Research on the Ecological Assessment System of Forest Dendrobium and *Panax pseudoginseng* Organic Cultivation and Forest Ecosystem Assessment System Research" (202102AE090042-03); the Yunnan Province "Xingdian Talent Support Program" Young Talent Special Program (XDYC-QNRC-2022-0205); the Yunnan Science and Technology Mission Innovation Guidance and Science and Technology Enterprise Cultivation Program for Guiding and Cultivating Science and Technology-based Enterprises "Yunnan Province Linxiang District Forest Herb Industry Science and Technology Mission" (Project No. 202204BI090003).

Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to the funded projects not having been completed.

Conflicts of Interest: The authors declare no conflicts of interest.

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