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EFFECTS OF ECOLOGICAL RESTORATION PATTERNS ON RUNOFF AND SEDIMENT IN AN ABANDONED COAL MINE OF SOUTHERN CHINA

Evaluating the ecological economic benefits of different ecological restoration patterns in abandoned mines is important in ecological restoration study. Taking the abandoned coal mine in Luoshi Township of Fengcheng county, Jiangxi province, as a case, 4 different ecological restoration patterns (grapefruit with grass vegetation – Pattern I, pine with grass vegetation – Pattern II, grapefruit – Pattern III, and bare slope – Pattern IV) have been conducted to study the runoff and sediment yield under natural rainfall conditions. The results showed that the ecological restoration patterns and rainfall intensity can significantly affect runoff and sediment yield which increased as rainfall intensity increased: Pattern IV > Pattern III > Pattern II > Pattern I. For the optimal ecological restoration with Pattern I, the average runoff and sediment reduction was 59.01 and 77.1%, respectively, in all rainfall intensities. Multivariate analysis of variance (MANOVA) showed that runoff and sediment were significantly affected by ecological restoration pattern and rainfall intensity ($P < 0.05$). Correlation analysis of runoff and sediment yields indicated that the reduction effect on sediment yield increased with the decrease of runoff, and the relationships between runoff and sediment at different ecological restoration patterns could be fitted with a linear function. Moreover, the vegetation configuration that combines fruit farming with

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grass can be not only beneficial to control soil and water conservation but produce considerable economic and ecological benefits.

1. INTRODUCTION

Mining is an important mainstay industry of economic development in many countries. With the development of the energy economy, mineral resources are largely utilized [1]. The continuous growth of energy demand results in the overexploitation of natural resources, changes land use patterns, produces lots of greenhouse gases (GHG), and leads to environmental pollution [2]. Mining is currently considered one of the most destructive economic activities to natural ecosystems. It brings a variety of adverse effects on the environment such as complete destruction of native vegetation and thus wildlife extinction [3]. Coal is widely exploited as the primary energy resource for local economic and social development [3]. Underground coal mining activities can produce a great number of excess material (mine waste) which has a profound impact on the sustainable development of ecosystems [1].

The exploitation and utilization of coal resources can inevitably change the material circulation and energy flow, disrupt the balance of the original ecosystem, and arise a variety of ecological environment issues [2] such as heavy metal pollution, nutrient insufficient, pH change, soil structure destruction, erosion resistance of soil decreased, and biodiversity decrease [3]. Mostly underground coal mining disrupts the dynamic balance inside the Earth's crust, and that causes land subsidence, change in the groundwater level and soil degradation [4]. In recent years, the coal industry has expedited optimization and adjustment to cut overcapacity, which led to the shutdown of many coal mines and the number of abandoned coal mines increased [5]. According to statistics from the China Coal Industry Association, more than 80 000 coal mines in China in the peak period have been eliminated to about 5800 at the end of 2018 [6]. Therefore, the restoration of abandoned coal mines is a very urgent task. Considering the urgency of ecological restoration, the United Nations General Assembly declared 2021–2030 the UN Decade on Ecosystem Restoration [7]. The restoration of degenerated soil in coal mining areas can improve the current situation of terrestrial ecosystems and achieve sustainable development [8, 9].

Recently, researchers have taken various measures to restore degraded soil in coal mining areas. Ecological restoration of abandoned coal mine refers to restoring the essential ecosystem service and biodiversity [10]. Vegetation in the abandoned coal mine is conducive to restraining coal dust diffusion, sedimentation, and finally improving the value of soil services [11]. The vegetation restoration of degraded land is a main link to improving environmental quality, which can recover the plant community, reduce soil erosion [10]. Numerous studies showed that vegetation could effectively store water and reduce sediment, and was also a main factor in improving soil and water conservation [12]. Vegetation restoration played a crucial role in soil organic matter increase and soil physical structure improvement, and accordingly rainfall infiltration promotion, runoff and sediment yields reduction [13].

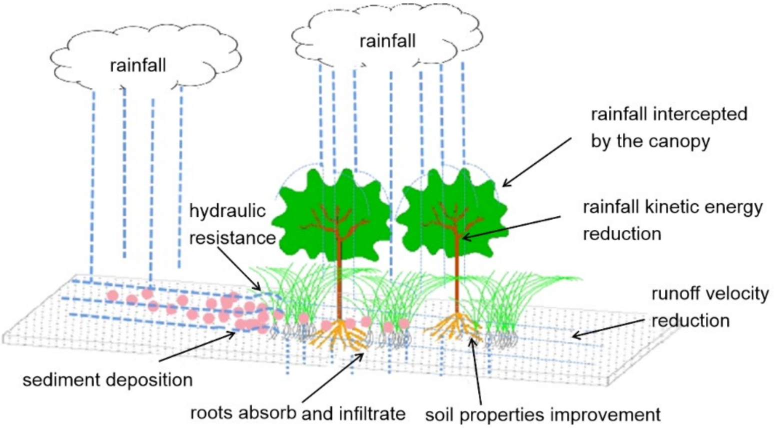

Fig. 1. Effects of arbors combined with grasses on runoff and sediment processes

Its controlling effects on soil and water conservation processes are mainly manifested from 4 aspects (Fig. 1): (i) leaves and stems can help increase the amount of rainfall intercepted by the canopy, (ii) and reduce rainfall kinetic energy, (iii) root and litter layer can increase the rainfall absorption and the soil infiltration, (iv) thus there is an increase of surface roughness accelerate sediment deposition, (v) and increase of hydraulic resistance, (vi) and reduction of runoff velocity, (vii) the plant roots are enhanced and the soil physical and chemical properties are improved [14, 15]. Moreover, the multiply vegetation structure forest had more effective control of soil erosion compared with the pure forest, and vegetation the same canopy cover had different water and soil conservation benefits [16]. Therefore, vegetation restoration reduces soil erosion through its different spatial arrangement, especially the near ground layer such as roots and litter layer had greater effect than that of canopy cover. Previous studies mainly focused on the effects of vegetation coverage, the spatial distribution pattern of vegetation, and the runoff and soil erosion. These studies played an important role in ecological restoration and controlling soil and water conservation. However, most of them were conducted in the laboratory, which was immensely different from the actual situation because the vegetation was not growth in a natural condition. And there are relatively few studies focused on the ecological restoration pattern (species composition, like fruit tree combine with grass) which can control soil erosion and generate economic benefits, the studies on which have both scientific and practical significance.

In this paper, the process of soil erosion at different ecological restoration patterns of abandoned coal mines was conducted through a field plot runoff experiment. The aims of this study were: (i) to study the characteristics of runoff and sediment during nature rainfall conduction, and compare the effect of runoff and sediment reduction among different patterns, (ii) to clarify the contributions of fruit farming combined with grass vegetation to soil erosion, (iii) to explore the most suitable ecological restoration pattern which can not only control soil and water conservation but also bring economic benefits. It is expected to provide scientific base for abandoned coal mines ecological restoration in case study area.

2. MATERIALS AND METHODS

Study area. The mining wasteland was located in Luoshi Township of Fengcheng county, Jiangxi province, (115°51′18″–115°51′40″ E, 27°58′18″–27°58′33″N) at an altitude of 50–105 m. The area had a subtropical humid climate, with an average annual temperature of 15.3–17.7 °C, average annual rainfall of 1552.1 mm. Its precipitation was primarily concentrated from May to July in the form of heavy rains, accounting for about half of the annual rainfall. The study area belonged to the hill denudation landforms, in which dominated soil type was red soil. The vegetation was dominated by pine trees and shrubs.

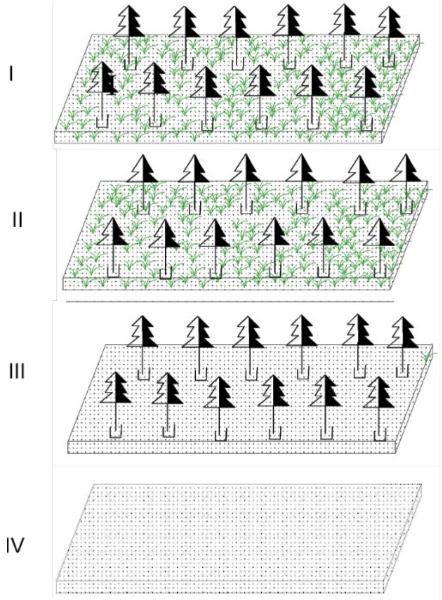

Fig. 2. Schematic diagram of runoff plot setting

Experimental setup. Four runoff plots were designed in this area, 10 m wide and 20 m long with a slope of 15°. Plants were planted in May 2015. Each restoration pattern was set up twice for repeated observation, including grapefruit with grass vegetation (Pattern I), pine with grass vegetation (Pattern II), grapefruit (Pattern III), and bare slope (Pattern IV) (Fig. 2). At the top and bottom of the runoff plot, impervious polyvinyl chloride (PVC) sheets were inserted perpendicularly for the enclosure, and diversion trough was set at the bottom to divert water into the collecting bucket to collect runoff and sediment. In this experiment, the soil erosion monitoring period lasted for 2 rainy seasons (from June to July in 2020 and 2021), and the runoff and sediment of each runoff plot was collected.

Data analysis. Excel 2010 was used to organize data. Based on SPSS 26 (IBM SPSS Statistics 26), multivariate analysis of variance (MANOVA) was used to analyze the significance of rainfall intensity and restoration patterns on runoff and sediment.

3. RESULTS

3.1. RUNOFF AND SEDIMENT UNDER DIFFERENT ECOLOGICAL RESTORATION PATTERNS

The runoff amount has been measured to describe the dynamic characteristics of the variation during rainfall. As the runoff was intercepted by vegetation, the runoff amount varied with the different ecological restoration patterns. The runoff amount in each rain event is shown in Fig. 3.

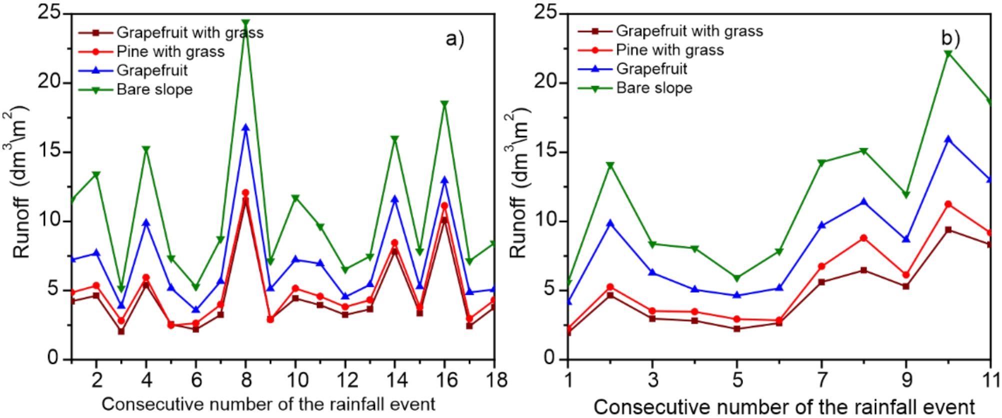

Fig. 3. Runoff process in different ecological restoration patterns:
a) rainy season in 2020, b) rainy season in 2021

Under Pattern I, the grapefruit with grass vegetation reduced the average runoff by more than half compared with the bare slope, and in the 2020 or 2021 rainy season, the runoff amount of Pattern I were both the lowest. Therefore, the reduction function of the grapefruit with grass vegetation was the best, the runoff flowed through the base of slope was the lowest, and the effect of runoff erosion was also the lowest among different ecological restoration patterns.

Table 1

Runoff amounts [dm^3/m^2] in different ecological restoration patterns under different rainfall intensities

Rainfall intensity	Grapefruit with grass	Pine with grass	Grapefruit	Bare slope
Rainy season in 2020				
Light rain	2.1±0.12	2.73±0.13	3.72±0.21	5.22±0.08
Medium rain	3.24±0.53	3.68±0.73	5.34±0.68	7.81±0.97
Heavy rain	5.29±1.48	5.95±1.45	8.72±1.93	13.6±2.02
Rainstorm	10.79±0.98	11.61±0.67	14.84±2.69	21.5±4.15
Rainy season in 2021				
Light rain	2.09±0.21	2.6±0.47	4.39±0.35	5.76±0.25
Medium rain	2.81±0.17	3.28±0.37	5.5±0.68	8.09±0.26
Heavy rain	5.51±0.75	6.73±1.50	9.9±1.12	13.88±1.34
Rainstorm	8.85±0.76	10.2±1.47	14.45±2.07	20.42±2.50

Table 1 shows the average runoff under different ecological restoration patterns in the rainy season of 2020 and 2021. The runoff reduction functions of different ecological restoration patterns decreased as follows: Pattern I > Pattern II > Pattern III > Pattern IV. The results suggest that the runoff reduction was the best when the ecological restoration pattern was planting grapefruit with grass vegetation in the abandoned coal mine slope. It could reduce average runoff amounts by 13.2% compared planting pine with grass vegetation, by 39.9% compared with planting grapefruit without grass, and by 58.7% compared with Pattern IV bare slope.

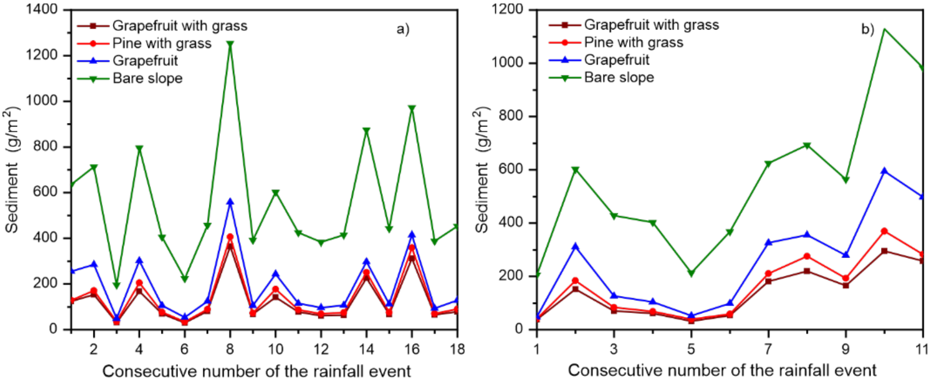

Fig. 4. Sediment process in different ecological restoration patterns:
a) rainy season in 2020, b) rainy season in 2021

As the runoff was intercepted by different vegetation, the sediment yield reduced with the runoff velocity reduction. The sediment yield of different ecological restoration patterns in the 2020 and 2021 rainy seasons is shown in Fig. 4. The grapefruit with grass vegetation (Pattern I) and pine with grass vegetation (Pattern II) reduced the sediment yield more significantly compared with grapefruit (Pattern III) and the bare slope (Pattern IV). The sediment yield reduction functions of Pattern I was the best in all rainfall intensities. This demonstrated that grapefruit with grass vegetation had better direct sediment interception function.

Table 2

Sediment yields [g/m^2] in different ecological restoration patterns under different rainfall intensities

Rainfall intensity	Grapefruit with grass	Pine with grass	Grapefruit	Bare slope
Rainy season in 2020				
Light rain	30.89±0.68	35.13±0.70	51.36±4.34	210.02±20.00
Medium rain	70.48±7.17	78.42±8.06	109.74±11.61	418.06±28.30
Heavy rain	162.96±38.84	186.81±45.38	276.83±26.03	724.73±112.83
Rainstorm	338.32±37.07	382.66±33.89	486.7±102.04	1113.55±199.79
Rainy season in 2021				
Light rain	35.05±4.38	39.67±1.20	50.19±3.47	209.2±5.73
Medium rain	61.97±8.49	70.19±12.52	109.62±14.33	399.41±30.27
Heavy rain	179.58±29.13	215.55±41.55	317.93±32.01	621.36±53.97
Rainstorm	276.18±24.24	326.29±61.59	546.22±67.95	1055.99±102.57

The sediment yield of different ecological restoration patterns under four rainfall intensities presented significant discrepancies compared with the bare slope control, and ecological restoration patterns had differences in reducing sediment yield (Table 2). The sediment reduction functions of Pattern I was the best. During different rainfall intensities, it could reduce average sediment yields by 13.2% compared with Pattern II, by 40.5% compared with Pattern III, and by 77.1% compared with Pattern IV. The sediment reduction functions of different ecological restoration patterns decreased as follows: Pattern I > Pattern II > Pattern III > Pattern IV.

3.2. CHARACTERISTICS OF RUNOFF AND SEDIMENT AT DIFFERENT RAINFALL INTENSITIES

Vegetation restoration patterns could effectively reduce runoff and sediment yields under different rainfall intensities [15]. The changes of rainfall intensity will lead to the changes of raindrops splash intensity. The changes in the average runoff with different ecological restoration patterns under various rainfall intensities were shown in Table 1 The results indicated that the average runoff amounts increased with rainfall intensities. The runoff increased obviously with the increase of rainfall intensity on Pattern IV and Pattern III. Other ecological restoration patterns (Pattern I, Pattern II, Pattern III) had beneficial roles in reduction runoff, in which Pattern I was the most effective. When the ecological restoration pattern was Pattern I, the runoff amounts varied from 10.79±0.69

to 2.09±0.15 under different rainfall intensities, with the runoff amounts being lower than that of Pattern II (2.6±0.34–11.61±0.047) and Pattern III (3.72±0.15–14.84±1.90). At the ecological restoration Pattern I, the runoff reduction during light rain, medium rain, heavy rain, and rainstorm were 61.9, 60.3, 60.7, and 53.15, respectively compared with Pattern IV, which were higher than in Pattern II (51.5, 54.6, 54.1, and 48%) and Pattern III (26.2, 31.7 32.7, and 30.2%).

In Table 2, the variations of sediment processes during different rainfall intensities have been shown. With the increase in the rainfall intensity, the sediment yield of each ecological restoration pattern increased but there were significant differences in sediment yield during different intensities in light and moderate rain intensities. Sediment yield reduction was more than 70% at ecological restoration Pattern I and Pattern II. When the rainfall intensity was high (heavy rain or rainstorm), the sediment yield reduction of the restoration patterns decreased. The sediment reduction was similar to the runoff reduction functions, with Pattern I being the best in all rainfall intensities. The sediment yield varied from 30.89±0.48 to 338.32±26.21 at different rainfall intensities, with the sediment yield being lower than that of Pattern II (35.13±0.49–382.66±23.96) and Pattern III (50.19±2.46–546.22±48.04). At the Pattern I, the average sediment reduction was 77.1% in all rainfall intensities compared with Pattern IV, which was higher than Pattern II (73.6%) and Pattern III (61.6%).

3.3. INTERACTION EFFECT OF ECOLOGICAL RESTORATION PATTERNS AND RAINFALL INTENSITY ON RUNOFF AND SEDIMENT

To identify how runoff and sediment were affected by ecological restoration patterns as well as possible interactions with rainfall intensity, multivariate analysis of variance (MANOVA) was performed using ecological restoration patterns and rainfall intensities as two fixed factors. Both runoff and sediment were significantly affected by ecological restoration patterns and rainfall intensity ($P < 0.05$, Table 3). Almost all runoff and sediment showed significant influences from ecological restoration patterns and rainfall intensity and interaction, meaning that soil erosion depended on the combination of ecological restoration pattern and rainfall intensity.

The interaction of ecological restoration patterns and rainfall intensity showed significant differences on runoff and sediment. To study for differences between specific levels of interaction, the least significant difference (LSD) post hoc comparisons of runoff and sediment under different ecological restoration patterns were conducted (Table 4). In the 2020 and 2021 rainy seasons, a significant difference among the different patterns was consistent. There was a statistically significant mean difference in runoff among Pattern I, Pattern III, and Pattern IV in the 2020 rainy season (mean difference = –6.54, –3.17, $p = 0.000, 0.000$) and in the 2021 rainy season (mean difference = –7.37, –3.76, $p = 0.000,0.000$). There was no significant mean difference in runoff between Pattern I and Pattern II in both rainy seasons ($P > 0.05$).

Table 3

Results of multivariate analysis of variance
between rainfall intensity and ecological restoration patterns

Variable		Mean square	*F*
Runoff	RI	285.776	219.489
	ER	135.368	103.969
	RI × ER	10.862	8.343
Sediment	RI	447742.037	177.917
	ER	680416.712	270.373
	RI × ER	51915.178	20.629
Runoff	RI	169.131	139.882
	ER	110.168	91.116
	RI × ER	4.993	4.129
Sediment	RI	367049.727	396.753
	ER	335628.622	362.789
	RI × ER	21008.306	22.708

RI – rainfall intensity, ER – ecological restoration pattern.
Significance for all measuremants is 0.000.

Table 4

Least significant difference (LSD) post hoc comparisons of runoff
and sediment under different ecological restoration patterns

Var.	(I) ER	(J) ER	I–J	St. er.	*S*	Var.	(I) ER	(J) ER	I–J	St. er.	*S*
Rainy season June–July 2020						Rainy season June–July 2021					
Run-off	I	II	–0.55	0.380	0.152	Run-off	I	II	–0.92	0.469	0.061
		III	–3.17*		0.000			III	–3.76*		0.000
		IV	–6.54*		0.000			IV	–7.37*		0.000
	II	I	0.55		0.152		II	I	0.92		0.061
		III	–2.62*		0.000			III	–2.85*		0.000
		IV	–5.98*		0.000			IV	–6.45*		0.000
	III	I	3.17*		0.000		III	I	3.76*		0.000
		II	2.62*		0.000			II	2.85*		0.000
		IV	–3.36*		0.000			IV	–3.60*		0.000
	IV	I	6.57*		0.000		IV	I	7.37*		0.000
		II	5.98*		0.000			II	6.45*		0.000
		III	3.36*		0.000			III	3.60*		0.000
Sed.	I	II	–8.77	16.722	0.602	Sed.	I	II	–17.73	12.969	0.182
		III	–51.13*		0.003			III	–119.70*		0.000
		IV	–446.99*		0.000			IV	–388.85*		0.000
	II	I	8.77		0.602		II	I	17.73		0.182
		III	–42.36*		0.014			III	–101.97*		0.000
		IV	–438.21*		0.000			IV	–371.12*		0.000

Table 4

Least significant difference (LSD) post hoc comparisons of runoff and sediment under different ecological restoration patterns

	III	I	51.13^*		0.003		III	I	119.70^*		0.000
		II	42.36^*		0.014			II	101.97^*		0.000
		IV	-395.85^*		0.000			IV	-269.15^*		0.000
	IV	I	446.99^*		0.000		IV	I	388.85^*		0.000
		II	438.22^*		0.000			II	371.12^*		0.000
		III	395.85^*		0.000			III	269.15^*		0.000

I – pattern I: grapefruit with grass, II – pattern II: pine with grass, III – pattern III: grapefruit, IV – pattern IV: bare slope; Var. – variable, St. er. – standard error, Sed. – sediment, *S* – significance, asterisk (*) means $p < 0.05$.

Nevertheless, Pattern I significantly intercepted more runoff than Pattern II (mean difference = –0.55 and –0.92). The ecological restoration Pattern I had significantly higher efficiency in runoff reduction than Patterns II–IV did. The LSD post hoc test of sediment under different ecological restoration patterns was similar to the runoff. A statistically significant mean difference in sediment between Pattern I and Pattern IV was among the highest in the 2020 (mean difference = –446.99, $p = 0.000$) and 2021 rainy seasons (mean difference = –388.85, $p = 0.000$). There was also a significant difference in sediment between Pattern I and Pattern III. Although the sediment between Pattern I and Pattern II was no significant mean difference both in the 2020 and 2021, the mean difference between Pattern I and Pattern II was –8.77 and –17.73, respectively. Therefore, the ecological restoration Pattern I had significantly higher efficiency in sediment reduction than Pattern II, Pattern III, and Pattern IV did.

3.4. CORRELATION ANALYSIS OF RUNOFF AND SEDIMENT YIELDS

Slope runoff is the main driving force causing soil erosion. Exploring the response characteristics of sediment to runoff in different ecological restoration patterns has great scientific significance. The correlation coefficient between runoff and sediment in different ecological restoration patterns are shown in Table 5. There was a significant difference between the response characteristics of runoff and sediment of each ecological restoration pattern. The Pearson coefficients of determination (r) of all patterns were above 0.97, indicating that sediment and runoff of each pattern had a great correlation. Figure 5 shows the relationships between the runoff and sediment under different ecological restoration patterns. As the runoff increased, the sediment rate exhibited a linear ascending trend. The relationships between them could be fitted with a linear function $y = ax + b$, where y represents the sediment yields, g/m^2, x is the runoff, dm^3/m^2 with the coefficients a, and b (Table 5). More than 95% of sediment was determined by runoff ($R^2 > 95\%$).

Table 5

Correlation analysis of runoff and sediment yields under different ecological restoration patterns

Restoration pattern	Regression equation	R^2	Significance	Pearson correlation coefficient (r)
Grapefruit with grass	$y = 35.54x - 35.75$	0.9716	0	0.986
Pine with grass	$y = 37.67x - 52.34$	0.9657		0.987
Grapefruit	$y = 42.13x - 108.06$	0.9511		0.975
Bare slope	$y = 52.12x - 21.77$	0.9659		0.983

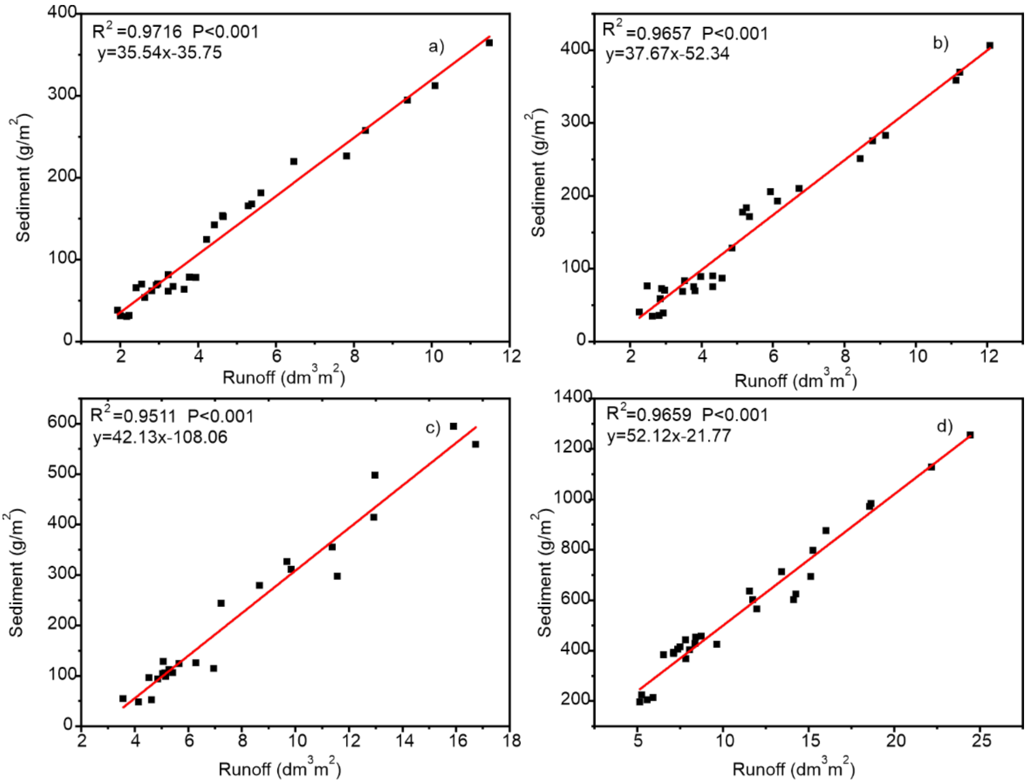

Fig. 5. Relationship between runoff and sediment in different ecological restoration patterns: a) pattern I (grapefruit with grass vegetation), b) pattern II (pine with grass vegetation), c) pattern III (grapefruit), d) pattern IV (bare slope)

The slope of all the ecological restoration patterns was positive, indicating that runoff had a relatively significant contribution to the sediment yield. For Pattern I, the slope was 35.54. Nevertheless, it increased to 37.67, 42.13, and 52.12 in Patterns II–IV, respectively. It indicated that the linear correlation between runoff and sediment yield of different ecological restoration patterns decreased as follows:

Pattern IV > Pattern III > Pattern II > Pattern I

That was, when the runoff was the same, the sediment yield was the highest in Pattern IV while the sediment yield was the lowest in Pattern I.

4. DISCUSSION

4.1. IMPACT OF ECOLOGICAL RESTORATION PATTERNS ON SOIL EROSION IN AN ABANDONED COAL MINE

Vegetation restoration can promote the restoration of ecological environment in the coal mining area, and control soil and water conservation. It plays a crucial role in reducing soil erosion processes. Because of various vegetation coverage and root biomass density, different vegetation restoration patterns have different effects on soil and water conservation [13]. The vegetation restoration can reduce raindrop energy and increase soil infiltration intensity via the root system, leading to the runoff velocity reduction and sediment transport capacity reduction. Besides, it can decrease the surface exposure and increase the surface roughness, lengthening the runoff path, and modified the runoff patterns, thus reducing soil erosion [17]. Furthermore, the crown of the vegetation changed the rainfall interception effect, attenuating the splash effect of raindrops on topsoil, and thus increasing rainfall infiltration to the soil [18]. In this study, through the analysis of runoff and sediment under different ecological restoration patterns in coal mining areas, differences in runoff and sediment amounts were found between vegetation reclamation areas and bare slopes. The results showed that grapefruit with grass vegetation (Pattern I) presented more significant effects than the other patterns on runoff and sediment during different rainfall intensities, The runoff reduction functions of different ecological restoration patterns decreased as follows: Pattern I > Pattern II > Pattern III > Pattern IV. The ecological restoration Pattern I could best reduce runoff and sediment yield by a maximum of 58.7 and 77.1, respectively, compared with Pattern IV. Other studies similarly revealed that in orchards of Chilean avocado retaining grass can effectively control soil erosion, and can reduce average runoff and sediment yield by a maximum of 61.1 and 99.5%, respectively [14]. Vegetation like arbors and grasses can significantly promote soil physical and chemical properties, and improve water infiltration velocity. Nevertheless, different vegetation types had different effects on the reduction of runoff and sediment. Sun et al. [19] studied the runoff and sediment loss rates of five vegetation types, they found that the arbor trees type was the best for soil and water conservation, and the arbors on soil controlling soil and water conservation have been verified in various areas. Jia et al. [20] found that the combined effect of planting grass and shrub could achieve a highly efficient runoff and sediment reduction effect. The laminated vegetation community was able to effectively reduce runoff and soil erosion compared with the single species community [16]. The benefits of arbor-grass in soil and water conservation can be attributed to a large canopy, surface grass, litter layers, and root system [19]. A dense canopy was effective in intercepting rainfall, and reducing runoff, and litter layers can be decomposed into the surface soil and affect soil erosion. Meanwhile, arbor-grass had developed a root system which can fix the soil, thereby reducing soil erosion [20], and the grass vegetation can affect runoff and sediment through leaves and stems, and reduce runoff generation time [20]. In summary, arbors combined with grass vegetation can effectively control soil erosion, which is consistent with the results of this study.

4.2. IMPACT OF RAINFALL INTENSITY ON RUNOFF AND SEDIMENT

Although vegetation restoration patterns can effectively reduce runoff and sediment, rainfall intensity also played a crucial role in impacting runoff and sediment in abandoned coal mine [16]. Previous research found that at high rainfall intensity, the middle diameter of raindrops was huge, the kinetic energy correspondingly higher, and the strength of splash intensity of raindrops increased, which was more conducive to the generation of runoff and sediment [20]. At the high rainfall intensity, the vegetation effect of runoff and sediment reduction was decreased, and the interaction between rainfall and topsoil affected the runoff generation time of vegetation. So that the water infiltration decreased and the surface runoff increased [21]. In this study, the results indicated that the average runoff and sediment yields increased with increasing rainfall intensities. Under the ecological restoration Pattern I, the average runoff amounts varied from 2.09±0.15 to 10.79±0.69 dm^3/ m^2, while the average sediment yield varied from 30.89±0.48 to 338.32±26.21 g/m^2 depending on rainfall intensities. Other sauthors also found that a positive correlation between runoff, sediment, and rainfall intensities [14]. Wei et al. [22] found that the higher rainfall intensities could generate earlier runoff start-time and higher peak runoff velocity, which caused strong soil erosion. On one hand, high rainfall intensity enhanced raindrops potential energy and soil splash erosion, which could promote soil particles smashed and stripped. On the other, the smashed and stripped soil particles formed sediment flow under the action of runoff erosion, which caused soil erosion [23]. In addition, as the runoff increased, the sediment rate exhibited a linear ascending trend at different ecological restoration patterns, similar to the results found by Shi et al. [15]. Furthermore, the results indicated that the equation slope (a) of the linear function was increased as the rainfall intensity was higher. At the high rainfall intensity, the runoff amounts were large and the sediment yields were more severe, resulting in a large amount of soil erosion.

4.3. SUGGESTIONS ON ECOLOGICAL RESTORATION OF ABANDONED COAL MINES

Based on the current situation in China, ecological restoration such as planting trees, tillage or grass on rights sites should be a good choice to restore abandoned mines. The purpose of abandoned coal mine ecological restoration was to give priority to agricultural land. The fruit farming reclamation pattern was the best ecological restoration measure on abandoned coal mine. Fruit tree not only has the high economic benefits but also has good effect on soil and water conservation. In this study, grapefruit trees with grass vegetation can achieve effective soil and water conservation, improving ecosystem productivity with economic benefits.

In abandoned coal mines, a vegetation configuration that combines fruit farming with grass vegetation was worthy of consideration for ecological restoration. This vegetation configuration pattern can improve the ecological environment quality, and form a fruit-based industrial chain. This was not only beneficial to control soil and water conservation and non-point source pollution reduction, but can produce both considerable economic benefits and ecological benefits.

5. CONCLUSION

In this study, the runoff and sediment yield of abandoned coal mines at different ecological restoration patterns under natural rainfall conditions were investigated to explore the optimal ecological restoration patterns. Runoff and sediment yield were considerably affected by ecological restoration patterns. Grapefruit with grass vegetation (Pattern I) produced lower runoff and bare slope sediment yield, while pine with grass vegetation (Pattern II), grapefruit vegetation (Pattern III), and bare slope (Pattern IV) had higher runoff and sediment yield. Fruit farming combined with grass vegetation played a crucial role in controlling soil erosion. The effect of rainfall intensity on the runoff and sediment yield was a significant difference in different ecological restoration patterns. When rainfall intensity increased, the runoff and sediment yield from all the ecological restoration patterns tended to increase. The relationships between runoff and sediment yield at different ecological restoration patterns could be fitted with a linear function, whose slope can be interpreted as the sediment yield to reflect the sensitivity of soil erosion. Soil erosion intensified as rainfall intensity increased and Pattern I had less soil erosion among all ecological restoration patterns. Vegetation configuration was of great significance in controlling soil and water conservation. From this point of view, vegetation configuration that combined fruit farming with grass should be paid enough attention to abandoned coal mines ecological restoration in China currently.

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