Effects of Different Inflow Rate Patterns and Distributions of Grass Strips on Runoff and Sediment in an Engineering Accumulation Body

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Abstract

Engineering accumulation bodies are critical sources of artificial soil and water loss. The objectives of this study were to evaluate the effects of different inflow rate patterns and distributions of grass strips on runoff and sediment in engineering accumulation bodies. A field runoff plot (20 m long, 1 m wide, and 0.5 m deep) was used for inflow simulation experiments under four inflow rate patterns (even, rising, falling, and rising-falling) and five grass strip patterns (patterns 1-5). The results showed that the changing trends of runoff rate and sediment yield increased with increasing inflow rate and decreased with reduction for the same grass strip pattern. Although the inflow rate pattern affected runoff and sediment yield, it had no significant effect on the total runoff and sediment. The influence of the grass strip pattern on runoff and sediment was significantly higher than that of the inflow rate pattern. The runoff reduction and sediment reduction effects of grass strip patterns were 12.23 to 49.62% and 12.92 to 80.54%, respectively. When grass strips were distributed on a slope in bands (pattern 5), the soil and water conservation effects were ideal, reducing the average runoff and sediment by 44.98% and 58.09%, respectively. Sediment reduction caused by decreasing runoff (SR$_R$) was the main factor controlling erosion and sediment yield. This study can guide the configuration of vegetation control measures for soil and water loss in engineering accumulation bodies.

1. Introduction

Discarded soils from production and construction projects that make up engineering accumulation bodies are the main sources of new soil and water loss in China (Niu et al. 2019; Lv et al. 2019). Compared with the original landform, an engineering accumulation body has the characteristics of complex material composition, poor soil structure, steep slope, and weak erosion resistance, which easily lead to soil and water loss under heavy rain conditions. The soil and water losses from engineering accumulation bodies reflect typical anthropogenically accelerated erosion, which has the characteristics of high intensity, wide range, and great damage and is an important factor restricting the sustainable development of the economy and society, endangering the health of the regional ecological environment and causing environmental disasters (Cerdà 2007; Borrelli et al. 2017; Conforti and Letto 2020). Therefore, the study of soil erosion in engineering accumulation bodies has great significance for preventing and controlling soil erosion and establishing prediction models.

An engineering accumulation body is usually composed of two parts: the platform and the slope; these parts lead to soil erosion with different characteristic sources of water and sediment. The platform is the main accumulation area of runoff, and runoff from the platform is the main cause of soil erosion on the slope because upslope runoff is the agent of runoff energy transfer and sediment transport on the slope; runoff fundamentally changes the hydrological input conditions in the lower part of the slope, adjusts to distribute runoff erosivity, changes the development process of slope soil erosion, and aggravates the degree of soil erosion on the slope (Zhang et al. 2016). Therefore, studying the influence of runoff from the platform on slope soil erosion can provide a basis for controlling the sediment loss from an engineering accumulation body. Scholars have previously studied the erosion process along slopes (Peng
et al. 2014; Wu et al. 2018), the quantification of rills on slopes (Gómez et al. 2003; Shen et al. 2015; Di Stefano et al. 2017), the dynamic mechanism of slope erosion (Li et al. 2016; Wang et al. 2016), and the hydrodynamic characteristics of rill flow (Peng et al. 2015; Jiang et al. 2018). These studies have deepened people's understanding of slope soil erosion. However, most of the above studies are based on the condition of constant upslope runoff or rainfall and do not consider the influence of changes in the rainfall-runoff spatial-temporal pattern on slope erosion. Few studies have reported on the response of slope runoff erosion under the condition of variations in upslope runoff caused by uneven rainfall events. As a result, this lack is not conducive to a comprehensive understanding of the slope runoff erosion process.

Vegetation is considered the fundamental measure to prevent and control soil erosion and can weaken rainfall or runoff erosion, increase infiltration, reduce runoff, and improve soil resistance to erosion through plant diversity, vertical vegetation structures, and vegetation distribution patterns (Bartley et al. 2006; Martina et al. 2010; Nunes et al. 2011; Feng et al. 2018; Hou et al. 2020). It is difficult to determine how plant diversity controls runoff and soil loss because diversity interacts with other plant factors (Shrestha et al. 2010). Bare patches act as "sources", and vegetation patches act as "sinks" for intercepting runoff and sediment. Vegetation and bare patches form source-sink landscape patterns that can change the level of landscape connectivity, collect surface runoff and transport sediment (Mayor et al. 2008). Unreasonable vegetation patterns may aggravate soil erosion, and different vegetation spatial patterns are an important factor leading to differences in slope soil erosion (Feng et al. 2018). Although many studies have investigated the change response of slope soil erosion to the vegetation pattern, due to the complexity of "pattern-process", which is a frontier problem in the fields of geoscience and ecology, and the coupling effect of multiple factors related to changes in soil erosion, the effects of vegetation patterns on erosion and sediment yield are still unclear (Fu et al. 2005).

Here, the effects of different inflow rate patterns and distributions of grass strips on runoff and sediment in an engineering accumulation body were studied. A field runoff plot experiment was conducted with the specific aims of (1) clarifying the evolution characteristics of the processes of runoff and sedimentation from the engineering accumulation body under different grass strip patterns and inflow rates, (2) evaluating the runoff and sediment reduction effects of grass patterns under different inflow rates and identifying the grass strip pattern with the best soil and water conservation effects, and (3) exploring the effect of grass strips on sediment regulation capacity under different inflow rates in the engineering accumulation body.

2 Materials And Methods

2.1 Experimental site and soil samples

The field experiment was carried out at the Yangling Soil and Water Conservation Experimental Station of the Chinese Academy of Sciences on the Loess Plateau (107°59′36.12″ E, 34°19′24.84″ N) (Fig. 1). The station is located in the warm temperate semihumid continental monsoon climate zone. The average
annual precipitation is 637.6 mm, with more than 60% falling from July to October. The average annual temperature is 12.9 °C. An experimental slope was built on an artificial excavation surface in contact with the parent soil.

The tested soil was collected from abandoned soil produced by excavating slope engineering projects (Yang et al. 2019). The soil used in this experiment was silty loam with 11.02% sand (50 μm–2 mm), 61.42% silt (50–2 μm), and 27.56% clay (< 2 μm). To maintain the natural state of the soil, the soil was not passed through any sieve (Niu et al. 2020), but the organic litter layer, weeds, and gravel were removed from the soil.

2.2. Experimental design

The field scouring experimental setup included a water supply line, a constant barrel, a valve, a flow metre, a steady flow groove, and collecting barrels (Fig. 2). The experimental plot was 20 m in length, 1 m in width, and 0.5 m in depth. The inflow intensities could be adjusted through the valve opening sizes. The water was kept at a constant pressure to ensure uniform flow. A steady flow groove (1.0 m length, 0.5 m width, and 0.3 m depth) was located at the top of the plot. The experimental plot slope was 32°, a common slope for engineering accumulation bodies in the experimental region.

With the total amount of water held constant (900 L), four inflow rate patterns, including even (Fig. 3a), rising (Fig. 3b), falling (Fig. 3c) and rising-falling (Fig. 3d), were designed to indirectly reflect the time distribution characteristics of rainfall and the influence of underlying surface conditions on the confluence process (Zhang et al. 2016). The duration of the flow event was set to 45 min. The process of the flow event was divided into three stages: early period (0–15 min), intermediate period (15–30 min), and late period (30–45 min). According to previous tests and the unit discharge that occurred in the experimental region under the condition of a heavy rainstorm, the inflow rate was calculated and selected (Guo 2010). The four inflow rate patterns are shown in Fig. 3. Before the start of each test, the desired inflow rate was calibrated 3 times, and the test could be carried out only when the error was less than ±5%.

To simulate the engineering accumulation and ensure the consistency of the initial conditions of the slope, soil samples of 50 cm were placed into the runoff area by the tamping method. The soil bulk density was controlled at approximately 1.25 g cm⁻³, and the initial soil water content was controlled at approximately 22%. In the experiment, Bahraini grass (25%), Kentucky grass (25%), and Youmei grass (50%) were selected to form the grass strips. Field investigations found that these species are often used for engineering slope protection and greening. The sizes of the grass strips were 10 m×1 m and 1 m×1 m. Thirty days before the experiment began, the grass strips were transplanted to the experiment plot to grow naturally. Soil erosion can be effectively controlled when vegetation cover reaches 50% (Liu et al. 2008); therefore, the grass cover was set at 50% for this experiment. In this experiment, five spatial configurations of the grass strips included bare soil (Pattern a), the upper slope (Pattern b), the middle slope (Pattern c), the lower slope (Pattern d), and bands (Pattern e), which are shown in Fig. 4.
2.3. Measurements

For each experiment, the runoff production time was recorded with a stopwatch. Runoff samples were collected at 2 min (0-6 min) and 3 min (6-45 min) intervals, and the sampling times were recorded with a stopwatch. The experimental slope was divided into 5 observation sections with intervals of 4 m. The surface flow velocity of each section was measured across a distance of 2.5 m using a dye tracer (KMnO₄) method. The mean velocity was obtained by multiplying the velocity by the correction factor of 0.75 (Luk and Merz 1992). After the experiment, runoff samples were weighed and left to stand for 24 hours, and the supernatant was poured off. Then, the remaining sediment was left to dry at 105 °C to calculate the sediment yield. This process was repeated once for each experiment.

2.4. Data calculation and analysis

The degree of runoff control (C) refers to the proportion of infiltration to rainfall or inflow. Under the condition of pure soil, C is one of the indexes to reflect the soil infiltration capacity, and when erosion-control measures are arranged on the slope, the index can describe the surface runoff control capacity of these conservation measures. C is an index to reflect the amount of runoff produced on the slope. The larger the runoff is, the smaller the water infiltration, which can lead to a decrease in the ability of conservation measures to regulate and control slope runoff (Wu et al. 2010). C is calculated using the following formula:

\[
C = \frac{I - R}{I}
\]

where \( C \) is the runoff control degree, \( I \) is the total rainfall or inflow (L) and \( R \) is the total runoff of the slope (L).

The process of sediment erosion driven by runoff is restricted by the amount of runoff and the flow-sediment relationship. Soil and water conservation measures mainly affect soil loss by adjusting the amount of runoff and the flow-sediment relationship (Zhang et al. 2016, Zhang et al 2017, Zhang et al 2019). The change in sediment yield on the slope before and after implementing the control measures can be calculated by the following formula:

\[
\Delta W = W_1 - W_2 = Q_1S_1 - Q_2S_2 \\
= Q_1S_1 - Q_2S_1 + Q_2S_1 - Q_2S_2 \\
= S_1(Q_1 - Q_2) + Q_2(S_1 - S_2) \\
= S_1\Delta Q + Q_2\Delta S
\]

where \( \Delta W \) is the total sediment reduction (kg) after the measures take effect. \( W_1, Q_1, \) and \( S_1 \) are the sediment yield (kg), runoff (L), and sediment concentration (kg/L) without measures, respectively. \( W_2, Q_2, \) and \( S_2 \) are the sediment yield (kg), runoff (L), and sediment concentration (kg/L) with measures,
respectively. $\Delta Q$ is the amount of runoff change (L) after the measures take effect. $\Delta S$ is the amount of sediment concentration (kg/L) after the measures take effect. $S_1 \Delta Q$ is defined as the amount of sediment reduction caused by decreasing runoff (SR$_R$, kg). $\Delta SQ_2$ is defined as the amount of sediment reduction caused by flow-sediment relationship changes (SR$_S$, kg).

All data analysis was performed using the SPSS16.0 software (IBM Corp., Armonk, NY, USA). ANOVA (P<0.05) was used to compare significant differences in the responses of inflow rate patterns and grass strip patterns to runoff and sediment under the same conditions. Pearson correlation analysis was used to examine the correlations among the inflow rate and grass strip patterns and the runoff and sediment. All figures were plotted using the Origin 8.5 software (OriginLab Corp., Northampton, MA, USA).

3 Results

3.1 Runoff process

The runoff rates under different grass strip patterns and inflow rate patterns are shown in Fig. 5. With lengthened duration, the runoff rate shows an increasing trend in the initial stage, then fluctuates, and finally tends to stabilize (Fig. 5a). The change trend of the runoff rate with inflow rate is clear; i.e., it increases with increasing inflow rate and decreases with decreasing inflow rate (Fig. 5b, 5c, 5d). Regardless of the inflow rate pattern, the runoff rates of patterns ß, ß, ß, and ß are less than that of pattern ß.

3.2 Sediment process

The sediment yields for different grass strip patterns and inflow rates are shown in Fig. 6. With the delay in duration, the sediment yields of patterns ß, ß, ß, and ß show fluctuating trends from 0–28 min and tend to stabilize from 28–45 min. The sediment yield process of pattern ß is the most stable, changing in almost a straight line (Fig. 6a). Similar to the production process, the change trend of sediment with inflow rate is clear; i.e., it increases with increasing inflow rate and decreases with decreasing inflow rate (Fig. 6b, 6c, 6d). In general, regardless of the inflow rate, the sediment yield of pattern ß is higher than those of patterns ß, ß, ß, and ß.

3.3 Runoff and sediment characteristics

Runoff is significantly correlated with the inflow rate pattern (P < 0.05) but highly significantly correlated with the grass strip pattern (P < 0.01) (Table 1). In addition, Fig. 7a shows that runoff volume decreases as follows: rising-falling > rising > falling > even. The rising-falling pattern has the highest runoff volume, reaching 575.46 L, while the even pattern shows the lowest runoff volume at 405.38 L. There are no significant differences in runoff volume among different inflow rate patterns (P > 0.05). Figure 7b shows that runoff volume decreases as follows: Pattern ß > Pattern ß > Pattern ß > Pattern ß > Pattern ß; runoff
volume is highest for pattern \( \text{Ⅰ} \) (680.90 L) and lowest for pattern \( \text{Ⅳ} \) (384.78 L). There are significant differences in runoff volume among the different grass strip patterns (\( P < 0.01 \)).

| Variable               | Runoff (L) | Sediment (kg) |
|------------------------|------------|---------------|
| Inflow rate pattern    | 0.470*     | 0.192         |
| Grass strip pattern    | -0.633**   | -0.549*       |
| Interaction            | 0.156      | -0.057        |

Notes: *: Correlation is significant at the 0.05 level; **: correlation is significant at the 0.01 level.

The highest correlations are found between the sediment and grass strip patterns (Table 1). In addition, Fig. 7c shows that sediment yield decreases as follows: rising > rising-falling > falling > even. The rising pattern has the highest sediment yield, reaching 123.83 kg, while the same pattern also shows the lowest sediment yield at 94.8 kg. There are no significant differences in sediment yield among the different inflow rate patterns (\( P > 0.05 \)). Figure 7d shows that sediment yield decreases as follows: Pattern Ⅶ > Pattern Ⅵ > Pattern Ⅴ > Pattern Ⅳ > Pattern Ⅲ. Sediment yield is highest for pattern Ⅶ (175.70 kg) and lowest for pattern Ⅲ (71.94 kg). There are significant differences in sediment yield among the different grass strip patterns (\( P < 0.01 \)).

### 3.4 Runoff reduction and sediment reduction

Table 2 gives the values of C (runoff regulation degree), runoff reduction, and sediment reduction for Patterns Ⅰ, Ⅱ, Ⅲ, and Ⅳ with different inflow rate patterns. The calculation of runoff reduction and sediment reduction is based on the value of pattern Ⅱ as a reference value, and the values from the other vegetation patterns are compared against the reference values. The C values of grass strip patterns Ⅰ, Ⅱ, Ⅲ, and Ⅳ are larger than that of pattern Ⅱ, indicating that the infiltration amounts of patterns Ⅰ, Ⅱ, Ⅲ, and Ⅳ are larger than that of pattern Ⅱ, but the runoff values are less than that of pattern Ⅱ (Table 2). These changes occur because the grass strips distributed on the slope can effectively increase the resistance of slope flow, extend the residence time of the runoff on the slope and increase the infiltration of the slope. The mean C value is highest for pattern Ⅳ (0.57%), showing that the water infiltration of pattern E is the largest and that the associated runoff is lowest. Additionally, the value of C is related to the inflow rate pattern. When the inflow rate pattern is even, the C values of patterns Ⅰ, Ⅱ, Ⅲ, and Ⅳ are generally larger than those of the rising, falling, and rising-falling patterns. Changes in the inflow rate pattern cause changes in the infiltration capacity and the redistribution of runoff with time (Zhang et al. 2016).
Table 2
Results for C, runoff reduction, and sediment reduction under different inflow rate and grass strip patterns.

| Inflow rate pattern | Grass strip pattern | C (%) | Runoff reduction (%) | Sediment reduction (%) |
|---------------------|---------------------|-------|---------------------|-----------------------|
| even                | □                    | 0.32  | —                   | —                     |
|                     | □                    | 0.61  | 43.69               | 60.95                 |
|                     | □                    | 0.65  | 48.47               | 58.84                 |
|                     | □                    | 0.51  | 29.04               | 44.07                 |
|                     | □                    | 0.66  | 49.62               | 64.49                 |
| rising              | □                    | 0.16  | —                   | —                     |
|                     | □                    | 0.46  | 35.97               | 63.35                 |
|                     | □                    | 0.27  | 12.88               | 54.64                 |
|                     | □                    | 0.48  | 37.64               | 12.92                 |
|                     | □                    | 0.52  | 43.08               | 80.54                 |
| falling             | □                    | 0.31  | —                   | —                     |
|                     | □                    | 0.41  | 14.73               | 52.64                 |
|                     | □                    | 0.40  | 13.00               | 40.32                 |
|                     | □                    | 0.40  | 12.23               | 31.75                 |
|                     | □                    | 0.63  | 46.03               | 44.14                 |
| rising-falling      | □                    | 0.19  | —                   | —                     |
|                     | □                    | 0.41  | 27.80               | 40.70                 |
|                     | □                    | 0.32  | 17.04               | 27.41                 |
|                     | □                    | 0.40  | 25.91               | 39.82                 |
|                     | □                    | 0.48  | 41.17               | 43.18                 |

The runoff reductions of patterns □, □, □, and □ are from 14.73 to 43.69%, 12.88 to 48.47%, 12.23 to 37.64%, and 41.17 to 49.62%, respectively (Table 2). The average runoff reduction of the grass strip patterns decreases as follows: Pattern □ > Pattern □ > Pattern □ > Pattern □. The sediment reduction of patterns □, □, □, and □ are from 40.70 to 63.35%, 27.41 to 58.84%, 12.92 to 44.07%, and 43.18 to 80.54%, respectively. The average sediment reductions of grass strip patterns are similar to the average runoff reductions, with the sequence as follows: Pattern □ > Pattern □ > Pattern □ > Pattern □. These results indicate that the runoff and sediment reductions of pattern □ are optimal under different inflow rate patterns when the grass strip
is distributed on the slope in bands. Pattern \( \textcircled{6} \) has the best soil and water conservation effects and can reduce the average runoff and sediment by 44.98% and 58.09%, respectively.

### 3.5 Effects of grass strip patterns on sediment regulation capacity

The above research results show that the sediment reduction functions of grass strip patterns \( \textcircled{6}, \textcircled{7}, \textcircled{8}, \text{ and } \textcircled{9} \) are better than those of the runoff reduction functions for different inflow rate patterns. The runoff and sediment reductions of pattern \( \textcircled{6} \) are optimal (Table 2). Therefore, to further understand the sediment regulation capacity of the grass strip pattern, taking pattern \( \textcircled{6} \) as an example and applying Eq. 2, the amount of sediment reduction coming from the decrease in runoff and the adjustment of the flow-sediment relationship are obtained (Table 3).

| Inflow rate pattern | Grass strip pattern | Total sediment reduction (kg) | SR\(_R\) (kg) | SR\(_S\) (kg) |
|---------------------|---------------------|-------------------------------|---------------|---------------|
| even                | \( \textcircled{6} \) | 112.52                        | 91.85         | 20.67         |
| rising              | \( \textcircled{7} \) | 157.11                        | 80.91         | 76.20         |
| falling             | \( \textcircled{8} \) | 68.78                         | 73.99         | -5.21         |
| rising-falling      | \( \textcircled{9} \) | 76.63                         | 63.36         | 13.27         |

Table 3 gives the sediment-reducing capacity of Pattern \( \textcircled{6} \) under different inflow rate patterns. The total sediment reduction of pattern \( \textcircled{6} \) ranges from 68.78 to 112.52 kg for different inflow rate patterns, indicating that sediment reduction is affected by the inflow rate pattern. Sediment reductions caused by decreasing runoff (SR\(_R\)) and flow-sediment relationship changes (SR\(_S\)) range from 63.36 to 91.85 kg and -5.21 to 76.20 kg, respectively. These results indicate that SR\(_R\) is the main factor controlling erosion and sediment yield for pattern \( \textcircled{6} \).

### 4. Discussion

#### 4.1 Effects of inflow rate and grass strip patterns on runoff and sediment

The processes of runoff and sediment yield on the slope of the engineering accumulation body are affected by the inflow rate pattern. Inflow rate patterns cause the change in the infiltration capacity and the redistribution of runoff with time. In addition, a variable inflow rate pattern can increase or decrease the runoff detachment and sediment transport capacity on the slope and hasten or delay the transition from detachment-limited erosion to transport-limited erosion (Zhang et al. 2016). Therefore, changes in runoff and sediment yield are observed (Fig. 5, Fig. 6).
The runoff is the smallest under the even pattern; the variable inflow rate pattern can increase the runoff but has no significant effect on the runoff (Fig. 7a), which is similar to the observed results of studies under variable storm patterns by Frauenfeld and Truman (2004) and Parsons and Stone (2006). Zhang et al. (2016) suggested that the influence of the inflow rate pattern on slope runoff formation is limited; only by changing the water supply process temporally can slope runoff be redistributed over time. The correlation coefficient value between the grass strip pattern and the runoff is larger than that between the inflow rate pattern and runoff, which demonstrates that the influence of the grass strip pattern on runoff is significantly greater than that of the inflow rate pattern, because when the discharge increases or the peak flow changes, the micro-geomorphological connectivity of vegetation with different patterns is blocked; abrupt changes in slope velocity increase, and the impact on slope runoff yield depends on the ability of vegetation to disperse runoff and change the runoff path and on consistency between the relative positions of vegetation and the runoff path. This relationship is also the reason why the grass strip pattern has a significant impact on runoff (Fig. 7b).

The sediment yield of the even pattern is the smallest, and that of the rising pattern is the largest. A variable inflow rate pattern causes irregular changes in slope hydrodynamic conditions, affects the denudation-transport process of slope erosion, and finally influences the sediment yield, but it has no significant effect on the sediment yield (Fig. 7c). The grass strip pattern has a significant impact on sediment yield (Fig. 7d). Additionally, the correlation coefficient value between the grass strip pattern and the sediment yield is larger than that between the inflow rate pattern and the sediment yield, indicating that the different distributions and locations of grass strips on the slope are important reasons for the differences in soil erosion on the slope. Our results are consistent with those of You et al. (2005), who studied the effect of vegetation patterns on rainfall erosion.

4.2 Effect of grass strip pattern on runoff and sediment reductions

In general, the runoff reductions of grass strip patterns , , , and  are weaker than the sediment reductions for different inflow rate patterns (Table 2); this finding is consistent with that of a study by Zhang et al. (2014), who suggested that grasslands conserve soil and water by regulating runoff and sediment based on direct sediment interception when sediment is trapped by the surface vegetation canopy. Grass can increase infiltration, reduce runoff velocity Li and Pan (2018), and change the distribution characteristics of hydrodynamic parameters to some extent Pan and Shangguan (2006). Grass allocation plays a role in dispersing and reducing runoff erosion energy, thus regulating erosion and sediment production of the slope.

Compared to other grass strip patterns, Pattern blocks runoff many times, decreases the runoff velocity, increases infiltration (its mean C value is the highest), and reduces the runoff denudation ability by evenly distributing water on the slope. Thus, pattern has the best soil and water conservation effects and can reduce the average runoff and sediment by 44.98% and 58.09%, respectively. These results are similar to those reported by Valentin et al. (1999) and Raya et al. (2006). Valentin et al. (1999) suggested that a
banded pattern is the best choice for vegetation restoration design in arid and semiarid areas and can increase biomass and limit land degradation. Raya et al. (2006) considered that vegetation strips can effectively reduce runoff and erosion, and different vegetation types have different effects. However, Li et al. (2007) reported that the soil and water conservation effects of pattern \( p \) (the grass strip is placed at the bottom of the slope) are better than those of other patterns. The reasons for the difference may be related to slope gradient, slope length, and grass strip area. In addition, compared with the scouring condition, the rainfall condition requires a certain time and slope length for the slope runoff to gather, and the runoff intensity at the bottom of the slope is often large, resulting in serious erosion.

### 4.3 Sediment-reducing capacity of grass strip patterns

On the one hand, grass strips themselves can directly intercept part of the sediment. On the other hand, grass strips give full play to the role of the "retarding zone"; they alleviate the flow velocity, decrease the erosion degree of the runoff to the slope, and reduce erosion. Soil erosion can be effectively controlled by the dual actions of retaining sediment and slowing flow. The sediment can be controlled by reducing the runoff and adjusting the flow-sediment relationship, which are two important aspects of runoff effects on the regulation of water and sediment. Our results show that sediment reduction caused by decreasing runoff (\( S_{R} \)) is the main reason for controlled erosion and sediment yield by pattern E (Table 3). This finding is similar to the results from a study of the sediment-reducing benefits of runoff regulation under engineering measures on the steep slopes of abandoned soil deposits in the Chinese Loess Plateau noted by Zhang et al. (2019). Zhang et al. (2019) reported that reducing runoff and controlling runoff and sediment are the main reasons why engineering measures restrain erosion and that sediment reduction caused by changes in the flow-sediment relationship (\( S_{S} \)) is restricted by sediment reduction caused by decreasing runoff (\( S_{R} \)).

### 5. Conclusions

Field scouring experiments were conducted on plots to explore the effects of four inflow rate patterns (even, rising, falling, and rising-falling) and five grass strip patterns (patterns 0-4) on runoff and sediment in engineering accumulation bodies. The results showed that the change trends of runoff rate and sediment yield increased with increasing inflow rate and decreased with decreasing inflow rate for the same grass strip pattern. Although the inflow rate pattern changed the process of runoff and the sediment yield, it had no significant effects on the total runoff and sediment. The influences of the grass strip patterns on runoff and sediment were significantly greater than those of the inflow rate patterns. The runoff and sediment reductions associated with grass strip patterns were 12.23 to 49.62% and 12.92 to 80.54%, respectively. When the grass strips were distributed on the slope in bands, they had the best soil and water conservation effects, reducing the average runoff and sediment by 44.98% and 58.09%, respectively. Sediment reduction caused by decreasing runoff (\( S_{R} \)) was the main factor controlling erosion and sediment yield.

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**Compliance with Ethical Standards**

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