Response Relationship Between Microtopographic Change and Erosion-Sediment Yield on Sand-Covered Slopes: Postprint

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Abstract

The development of slope microtopography reflects the intensity and variation processes of erosion. To quantitatively investigate the response between microtopographic changes and erosion on slopes under different sand cover thicknesses, three successive rainfall events were simulated under a rainfall intensity of 1.5 mm · min ¹. Using 3D laser scanning technology, the spatial variation characteristics of slope microtopography and soil erosion were analyzed, and the relationship between microtopographic variation amplitude and erosion amount was well fitted. The results showed that the average sediment concentration of the slope decreased with increasing rainfall events. The length of the main sediment-producing area on sand-covered slopes was approximately three times that of loess slopes, and the peak values of segment erosion amount were mostly distributed at the 4–6 m positions of the slope, whereas the erosion peaks on loess slopes were distributed at the 3–4 m positions. With increasing rainfall events, microtopographic factors on loess slopes increased significantly ($P<0.05$), while those on sand-covered slopes showed an overall increasing trend but not significantly ($P>0.05$). The microtopographic factors that responded most strongly to erosion on loess slopes and sand-covered slopes were surface incision depth and surface roughness, respectively. The response relationship between microtopographic variation amplitude and erosion amount was stronger on loess slopes than on sand-covered slopes; thus, other sensitive indicators should be sought to optimize the equation for sand-covered slopes. This study provides a certain reference for revealing the erosion mechanisms in wind-water composite erosion regions.

Full Text

Preamble

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1.2 Experimental Device

The rainfall simulation experiment was conducted using a device [Figure 1: see original paper] with a slope length of 4 m. Sand thickness treatments of 0 cm, 0.5 cm, 1.0 cm, and 1.5 cm were established, with the 0 cm treatment serving as the control. After 30 minutes of rainfall, surface topography was scanned using a 3D laser scanner. For the 1.5 cm sand thickness treatment, surface scanning was performed at 2-day intervals, while other treatments were scanned at 3-day intervals, with each scan repeated three times. The slope length was 13 m, with a measurement interval of 1 m and a measurement point spacing of 0.7 m. The slope gradient was set at 12°, and the rainfall intensity was 1.5 mm · min ^{1}.

1.3 Data Analysis Methods

Three primary analytical methods were employed in this study [19, 21]:

(1) Surface Roughness Index (R): The roughness index was calculated based on the ratio of actual surface area to projected area. The slope was divided into 1 m × 1 m grid cells (13 cells total), with measurements taken at 1 m, 2 m, ···, 13 m intervals to determine surface roughness. The calculation formula was:

$$R = \frac{S_{\text{actual}}}{S_{\text{projected}}}$$

where S_{actual} represents the real surface area and $S_{\text{projected}}$ represents the projected area.

(2) Surface Incision Index (SI): This index quantifies the degree of surface cutting. The formula is given as:

$$R = \frac{1}{\cos(S \times \pi/180)}$$

where S represents the slope gradient in degrees.

(3) Statistical Analysis: One-way ANOVA was used to test for significant differences among treatments, and Pearson correlation analysis was employed to examine relationships between variables. All statistical analyses were performed using SPSS 22.0, with ArcGIS 10.1 and Origin 2017 used for data processing and visualization.

2 Results

2.2 Sediment Yield and Erosion Amount

The comparison between measured sediment yield and erosion amount calculated from DEM data is shown in [Figure 2: see original paper]. Statistical analysis revealed significant differences among treatments ($P < 0.05$). For the 0.5 cm sand thickness treatment, surface roughness values were 15.66%, 16.94%, and 18.16% for 1, 2, and 3 days of rainfall simulation, respectively. Under 1.0 cm sand thickness, roughness values were 13.34%, 16.45%, and 14.25% for the same durations, showing the trend: 3 days > 2 days > 1 day > control. For the 1.5 cm treatment, roughness values were 16.06% and 15.29% ([Figure 6: see original paper]).

2.4 Analysis of Influencing Factors

The relationship between micro-relief variation and erosion amount was analyzed using three consecutive rainfall simulations. The results indicated that as the number of rainfall events increased, average sediment concentrations on the slope decreased. The main erosion area on sand-covered slopes was approximately three times that on loess slopes, with peak erosion occurring at the 4–6 m position on the slope, while peak erosion on loess slopes occurred at the 3–4 m position.

Micro-relief factors on loess slopes increased significantly as the rainfall simulation progressed ($P < 0.05$), whereas those on sand-covered slopes increased but not significantly ($P > 0.05$). The study found that surface incision and surface roughness showed the strongest erosion response for loess and sand-covered slopes, respectively. The response relationship between micro-relief variation and erosion was stronger for loess slopes than for sand-covered slopes, suggesting that other sensitive indicators should be examined for sand-covered slopes to optimize predictive equations.

The correlation coefficient between erosion amount and micro-relief variation ranged from 0.788 to 0.831 ($P < 0.05$), indicating a significant positive correlation.

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Abstract: The development of slope micro-relief reflects the intensity and process of erosion. To quantitatively study the response relationship between micro-relief variation characteristics and erosion amount, three consecutive rainfall tests with simulated precipitation of 1.5 mm · min 1 were conducted, and the spatial variation characteristics of micro-relief and soil erosion were analyzed using 3-D laser scanner technology. The relationship between the amplitude of micro-relief and erosion was well fitted. The results showed that average sediment concentrations on the slope were reduced as the number of rainfall events increased. The lengths of the main sand-predicted area on the sand-covered slope were about three times that of the loess slope, and peaks of the amount of erosion of the slope were mostly found at the position of 4–6 m on the slope, but the peaks of erosion on the loess slope were found in the position of 3–4 m. As the rainfall simulation progressed, the micro-relief factors of the loess slope increased significantly ($P < 0.05$), and the micro-relief factors of the sand-covered slope increased, but not significantly ($P > 0.05$). The study found that the micro-relief factors with the strongest erosion response to the loess slope and the sand-covered slope were surface incision and surface roughness, respectively. The response relationship between micro-relief variation and erosion of the loess slope was stronger than for the sand-covered slope, so the sand-covered slope should be examined for other sensitive indicators to optimize the equation. This study provides reference information for determining the erosion mechanism of wind-water erosion across the region.

Keywords: sand-covered slope; erosion; spatial distribution; micro-relief; sand content; soil erosion

Note: Figure translations are in progress. See original paper for figures.