Model Experiment Study on the Anti-Erosion Capacity of Loess Slope Considering Moss Biocrust Coverage and Slope Gradient

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Abstract: Moss biocrusts play a significant role in enhancing the anti-erosion capacity of loess slope. The coverage of moss biocrusts and the slope gradient may be key factors controlling soil erosion on loess slopes. To investigate the ecological protection effect of moss biocrusts on loess slopes, this study conducted erosion experiments on loess slopes with different angles under moss biological crusts of various coverages. The controlled variables included moss biocrust coverage rate and slope angle. The moss biocrust coverage rates were 0%, 30%, 60%, and 90%, while the slope angles were 30°, 45°, 60°, and 75°. The results show that moss crusts can delay the initiation of runoff, hinder the velocity of runoff and sediment transport, and utilize their spring-like form to reduce the impact force of raindrops on soil particles. Compared to bare soil slopes, slopes covered with moss crusts exhibit significantly reduced erosion damage areas and significantly lower sediment yield (0.0963 kg·m^{-2}-43.7185 kg·m^{-2}). Considering the combined effects of crust coverage and slope steepness, this study preliminarily established a soil erosion equation based on moss crust coverage and slope gradient: $z = -0.4102 + 0.0119x + 0.3991\exp(-0.7060y)$. When the crust coverage reached a critical threshold of 60%, the improvement in slope erosion resistance reached its maximum, after which the rate of improvement gradually declines. The research findings provide crucial reference data for promoting the application of moss biocrusts in the Loess Plateau region to implement sustainable soil and water conservation practices and strengthen ecological slope protection.

Keywords: ***Loess slope; Moss crusts; Slope erosion; Coverage threshold; Model experiment; Ecological slope protection***

Introduction

Through a series of rainfall model experiments, the erosion of moss crust slopes under different coverage and slope gradients was investigated. The objectives of this study were to: (1) analyze the effects of moss crust coverage and slope gradient on slope erosion; (2) determine the quantitative relationships between moss crust coverage, slope gradient, and sediment yield on the slope; and (3) reveal the mechanisms by which moss crust and slope gradient alter the slope's erosion resistance. In this study, we hypothesized that the coverage of moss crust and the slope gradient of the side slope can significantly affect the slope's erosion resistance, and that there are quantitative relationships between coverage, slope gradient, and sediment yield.

Materials and methods

Soil and moss crust samples were collected from Pucheng County, Shaanxi Province, China (109°20'17"-109°54'48"E, 34°44'50"-35°10'30"N). All soil and moss crust samples were collected from several typical loess slopes, within the upper 30 cm of the slope surface. The collected loess was typical Malan (Q_3) loess. The dominant moss species distributed on the slope was *Racomitrium*, with moss crust coverage ranging from 30% to nearly complete coverage.

The indoor scour test was conducted at the Pucheng Test Base to investigate the erosion resistance of slopes. A simulated rainfall device was used to generate artificial rainfall (Figure 1). All the model experiments in this study used a constant rainfall intensity of 120 mm·h-1 and a duration of 40 minutes to simulate the extreme rainfall events that have occurred within Shaanxi Province.

The design slopes for the model experiments were set at 30°, 45°, 60°, and 75°, with moss crust coverage rates of 0%, 30%, 60%, and 90%, which align with the actual slope conditions and moss coverage in the area.

Results

Variations in moss crust coverage exerted a notable influence on slope erosion. In the absence of moss crust, rainfall induced considerable damage to the slope surface, leading to the manifestation of the largest eroded area. Conversely, the presence of moss crust markedly enhanced the slope's resistance to erosion. As the moss crust coverage increased, a gradual reduction in the eroded area was observed, thereby effectively mitigating the occurrence of large-scale erosion events.

The slope gradient exerted a notable influence on the patterns of erosion observed. Specifically, on gently inclined slopes with a gradient of approximately 30°, rainfall induced minimal erosion damage, manifesting in a comparatively smaller extent of eroded area. As the slope gradient increased to 45°, a discernible enlargement in the eroded area was evident. This upward trend persisted with further augmentation in the slope gradient, reaching 60°, where the eroded area expanded further. Ultimately, the most pronounced erosion was observed on the steepest slopes, with a gradient of 75°, which were characterized by the most extensive eroded area, indicating the severity of erosion under such extreme slope conditions.

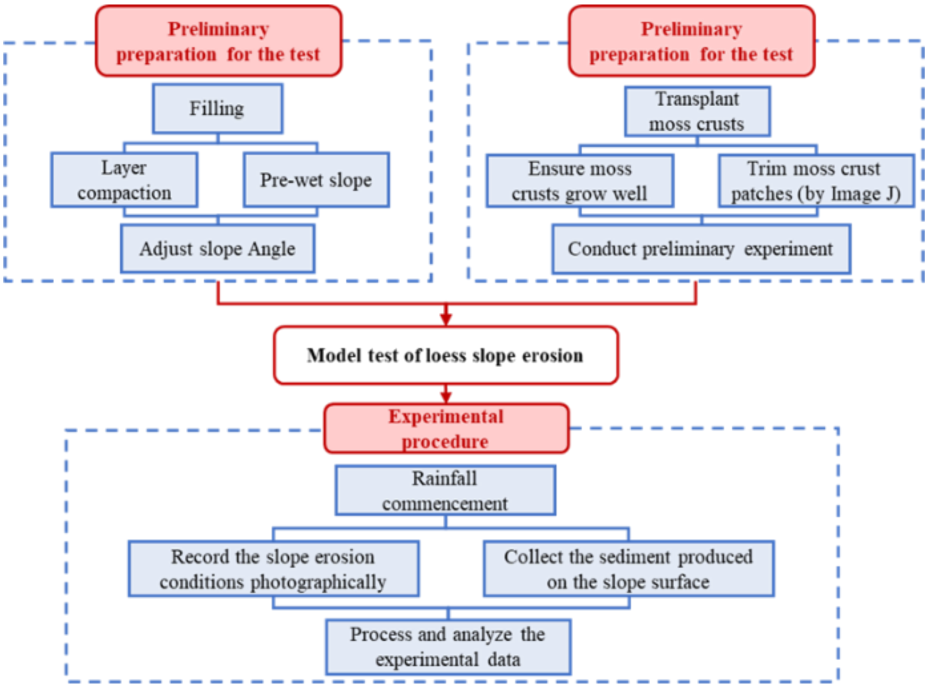

Figure 1, Model preparation and experimental procedure.

Discussion

Above results highlight the crucial role of moss crust coverage and slope gradient in influencing soil erosion (An et al., 2012; Belnap, 2006). Understanding the relationship between these factors and erosion rates is vital for predicting soil loss on the Loess Plateau and for incorporating biocrust effects into soil erosion models. Based on the data results from our 16 sets of model experiments, and further validated by research data from other investigators, we developed a preliminary equation to estimate soil erosion rate (z, in kg·m^{-2}·min^{-1}) using moss crust coverage (y, in %) and slope gradient (x, in °):

$$z = -0.4102 + 0.0119x + 0.3991exp(-0.7060y)\ (R^2 = 0.7013, P < 0.005)$$

This equation emphasizes the combined influence of slope and coverage on soil erosion. It suggests that solely focusing on maximizing crust coverage might not be the most effective approach. Instead, a balanced strategy considering both factors is crucial. For instance, on gentler slopes, moderate crust coverage might suffice for adequate protection while ensuring cost-effectiveness. However, further investigation is needed to validate this equation for extremely gentle (<15°) or steep (>75°) slopes, and for coverage exceeding 90%.

Conclusion

There exists an optimal "threshold of well-performing moss crust coverage" centered around 60%. The present study employed a transplantation method for establishing moss biocrusts in the model experiments. Conducting in situ experiments with naturally growing moss biocrusts may yield even more robust results, warranting further investigation. Overall, this research provides a valuable reference for predicting soil erosion dynamics, informing the implementation of targeted slope ecological protection, and promoting sustainable development in the Loess Plateau and other arid to semi-arid regions.

References

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