Effects of Polyacrylamide on Runoff and Sediment Characteristics of Slope in Northeast Black Soil Area

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Abstract. Soil erosion caused by hydraulic erosion has become the main driving force to destroy the ecosystem and has become a worldwide environmental problem. The effect of polyacrylamide (PAM) on slope erosion characteristics in black soil area was studied under different conditions. The method of artificial simulation of rainfall was adopted. At 4 slopes and 5 PAM concentrations, the rainfall lasted 60min and the rainfall intensity was 80mm/h. The results show that when the rainfall intensity and underlying surface conditions are the same, the slope increases from 10° to 25°, the average runoff on the slope increases first and then decreases, and the sediment yield increases with the increase of the slope. The sediment yield on the 25° slope is 1.64 times that of the 10° slope. With the same rainfall intensity and slope compared with bare land, the concentration of Polyacrylamide in 2g / m² increased to 5g / m², and the average yield decreased by 10.6% to 20%. The average sediment yield decreased with the increase of the concentration, which was 20.4%~52.5% lower than that of the bare land. The variation law of PAM and bare slope sediment yield can be described by power function. Compared with the total sediment yield of PAM and bare slope, PAM is obviously decreased. The bare slope surface is mainly characterized by splash erosion and surface erosion. The application of PAM can reduce the erosion area of slope compared with bare slope, which plays an important role in corrosion prevention.

1. Introduction

Hydraulic erosion is the most widely distributed and harmful type of soil erosion in the world. Surface erosion is a form of hydraulic erosion and the initial stage of slope runoff erosion. Among the many influencing factors of surface erosion, slope is one of the important factors [1-2], whose influence degree is second only to the vegetation coverage. Research on slope erosion process in black soil region shows that the amount of slope erosion increases with the increase of slope, while the change of slope runoff with slope is still controversial [3-5]. In recent years, chemical control measures have been introduced into the research of soil erosion control. PAM is a linear polymer compound, which is soluble in water and has a strong cohesive effect. In the loess plateau where soil erosion is serious, the application of
PAM is more important. As a soil structure modifier, its effects on increasing the cohesion of soil surface particles, maintaining soil structure, enhancing soil erosion resistance and reducing soil erosion have been proved by many studies [6-8]. Chen kechang et al. [9] found through the experiment of artificial rainfall runoff on sandy loam slope in the field that the application of PAM did have an effect on soil infiltration rate, but the amount of PAM could change the effect of PAM on soil infiltration rate. Large dosage can reduce soil infiltration rate and increase slope runoff. Cui haiying et al. [10] studied the coarse sandy soil and found that the application of PAM to different soils had different effects on soil yield and flow. The application of coarse sandy soil with poor structure would reduce soil infiltration rate and increase runoff, while the application of loam with good structure would increase soil infiltration rate and reduce runoff. According to the research results of relevant scholars, different application objects of the same PAM concentration have different effects on soil runoff. It can be seen that the soil types in different areas and the amount of PAM applied have different effects on the sediment production. Although there are many studies on the effect of PAM on soil erosion, there is still no unified conclusion on the effect of PAM dosage on sediment production due to different experimental conditions.

The effects of PAM concentration and slope on sediment yield and sediment transport on the powder loam slope of Songhua River basin in China were studied by outdoor simulated rainfall experiment.

2. Experimental design and methods

2.1. Experimental design

The test soil was taken from the slope of Songhua River Dike in Qianguo County, China, with a depth of 20cm. The mechanical composition of soil was determined by laser particle size analysis, with clay content of 6.82%, powder content of 58.70%, sand content of 34.48% and soil type of powder loam. Rainfall intensity was selected as 80mm/h. In the first group, the underlying surface condition was the PAM concentration 3g/m², and four different slopes were selected, respectively 10°, 15°, 20° and 25°. In the second group, the gradient was 15° and the underlying surface conditions were 5 different PAM concentrations, respectively 0g/m², 2g/m², 3g/m², 4g/m² and 5g/m².

The experiment adopts the rainfall simulation system, which uses the principle of oscillation to simulate the rainfall under natural conditions. Rainfall intensity 9.5 ~ 100mm/h, rainfall uniformity greater than 80%, rainfall area 2×5m², rainfall height 6m. The measuring range of handheld fast laser scanner is 0.15~4m, the resolution of laser head is 0.1mm, and the measuring speed is 550,000 times/s. The geomorphology was measured by feature splicing and marker point positioning, and the measured data was displayed by 3d graph. The portable slope-changing runoff tank is used for rainfall, with a length of 1.5m, a width of 0.4m and a depth of 0.4m, and a slope variation range of 0 ~ 30°. The bottom of the runoff tank is perforated evenly, which is conducive to rainfall infiltration.

2.2. Experimental methods

Impurities were removed from the test soil and air dried and mixed after passing 5.0mm screen. In order to simulate the real situation of river slope filling accurately, the layered filling method is adopted. Before filling the upper soil, roughen the surface of the lower soil to ensure that the two layers are closely connected and prevent separation. Before the experiment began, part of the soil and PAM particles were taken out and mixed evenly. After the soil in the runoff tank was roughed and sprayed with water, the evenly mixed soil was laid in the runoff tank and allowed to stand for 24h.

Before the start of simulated rainfall, four evaporating dishes are evenly arranged around the runoff channel to determine the rainfall intensity. According to the rainfall of each measuring point, the uniformity formula is used to calculate the rainfall uniformity. When the rainfall uniformity is greater than 80%, the test is started. The rainfall lasted for 1h, and the start time of runoff production was recorded. After the start of runoff production, runoff and sediment samples were collected once every 3min, each time for 10s, and the stopwatch was used for timing. After the rainfall, the laser scanner was used to scan the slope surface to obtain the three-dimensional surface data. Runoff and sediment yield both were estimated based on the collected muddy water samples.
2.3. Data analysis
Origin is used to draw the curve of runoff and sediment yield; Geomagic studio is used to process the three-dimensional point cloud data of slope surface to obtain the slope surface data; then the slope surface data is imported into ArcGIS for gray-scale mapping to extract the areas with serious erosion.

3. Results and analysis

3.1. Effect of PAM concentration and slope on runoff yield on slope

Figure 1 as the rainfall intensity and slope phase at the same time, the different underlying surface conditions with different degree of rainfall runoff yield rate volatility, but as the change of PAM concentration, the average runoff rate cut-off for 3 g/m², more than 3 g/m² production flow rate decreases with increasing concentration, concentration is less than 3 g/m² production flow rate increases with the concentration, the runoff rate 0 g/m² > 5 g/m² > 4 g/m² > 2 g/m² > 3 g/m². The analysis shows that within a certain range of PAM concentration, the soil infiltration channel can be opened, the soil infiltration rate can be increased, and the runoff can be reduced. Beyond this range, the soil infiltration rate decreases and the runoff increases.

Figure 2 shows that when the rainfall intensity and underlying surface conditions are the same, the trend of runoff generation rate of different slopes is significantly different. With the duration of rainfall, the trend first increases sharply, and then fluctuates in different ranges, but the overall trend increases. At the significance level of 0.05, one-way anova was used to find that the slope had a significant impact on the slope yield, which was 15°>20°>25°>10°. When the slope is large, the rain-exposed area decreases, and under the same infiltration condition, the runoff on the slope should gradually decrease in theory. However, in this test, the slope of 15° is taken as the cut-off point, and the yield of more than 15° decreases with the increase of the slope, while the yield of less than 15° increases with the increase of the slope.
3.2. Effects of PAM concentration and slope on sediment yield on slope

Figure 3 shows that with the same rainfall intensity and slope, sediment yield of different PAM concentrations changes significantly. The sediment yield rate of the slope with PAM concentration of 0g/m², 2g/m², 3g/m² and 5g/m² increased first with rainfall duration, and then fluctuated to different degrees, but did not become stable. The sediment yield of slope with PAM concentration of 4g/m² increased slowly with rainfall duration, and then tended to be stable. With the increase of PAM concentration, sediment yield of different slopes decreased gradually. At the significance level of 0.05, the analysis of sediment yield at different concentrations using one-way anova found that the concentration had a significant impact on sediment yield, that is, sediment yield was 0g/m² > 2g/m² > 3g/m² > 4g/m² > 5g/m².

Figure 4 shows that under the rainfall intensity of 80mm/h, the trend of sediment yield varies greatly at different slopes. The sediment yield on slopes of 10°, 15° and 20° increased sharply at first and then decreased slowly. The sediment yield of 25° slope increased sharply at first, and then fluctuated greatly. With the increase of slope, the sediment yield of slope increases. At the significance level of 0.05, the analysis of sediment yield of different slopes by one-way anova showed that the slope had a significant impact on sediment yield, that is, the sediment yield was 25° > 20° > 15° > 10°.

The influence of different slope and PAM concentration on sediment yield was fitted, and the following formula was obtained:

\[ Se = 0.0124S^{0.6898}C^{-0.3358} \quad (R^2 = 0.86, P < 0.05) \]

Se is the slope sediment yield, S is slope, C is the concentration. The variation law of sediment yield with rainfall duration can be described by power function. Sediment yield is positively correlated with slope. The higher the concentration, the smaller the sediment yield.
3.3. Morphological characteristics of slope erosion

![Gray scale of bare erosion](image1)
![Gray scale of PAM erosion](image2)

Figure 5. Different PAM concentration slope erosion gray scale

Hydraulic erosion shows different forms in different stages and affects sediment production and abortion at the same time. Therefore, it is of great significance to analyze the morphology of sediment production and abortion on slope. Under the same slope, bare land and PAM concentration 3g/m^2 were taken as an example for analysis. It can be seen from Figure 5 that the erosion of bare slope mainly occurs in the middle and upper part of the slope, and the erosion area of pam-applied slope presents a more uniform distribution. Both slopes are dominated by surface erosion accompanied by splash erosion. The serious areas of bare land erosion are mainly manifested as patchy, and the erosion areas are concentrated with a large area, and some of them show the characteristics of falling ridge. The erosion depth is between 24-48mm. The severely eroded areas of PAM slope are mainly scaly, and the severely eroded areas are relatively concentrated with a large area, and some of them show laminar characteristics. The erosion depth is between 21-36mm. By extracting the erosion area of the slope and taking the erosion depth ≥20mm as the extraction standard, it was found that the area of serious erosion of bare land was 0.29m^2, accounting for 48.9% of the slope area. The area of severe erosion of PAM slope was 0.13m^2, accounting for 22.2% of the slope area. After the application of PAM, the area of severe erosion of PAM slope decreased by about 54.6% compared with the bare land. The application of polyacrylamide reduces the degree of slope erosion, which indicates that the application of polyacrylamide can prevent slope erosion.

4. Conclusion

In view of the above experimental analysis, the following conclusions are drawn:

1. Under the same slope, the average sediment yield rate of slope with PAM concentration 3g/m^2 decreased by 23.64% and the average runoff yield rate decreased by 16.78% compared with that of slope with 0g/m^2. The application of PAM with appropriate concentration on bare land enhances the infiltration capacity of soil, reduces runoff, weakens erosion and reduces erosion. With the increase of PAM concentration, the average sediment yield of slope decreases by 20.42%~52.49%. The average flow rate of slope decreases first and then increases. In this test, slope runoff yield was the smallest and soil infiltration effect was the best when PAM concentration was 3g/m^2.

2. With the same underlying surface condition, the average sediment yield increases with the increase of slope. The average flow rate is greatly affected by the slope. The turning point is 15°, which first increases and then decreases, and the change is obvious from 10° to 15° and from 20° to 25°.

3. Slope erosion forms are mainly splash erosion and surface erosion. The application of PAM can effectively control erosion. It has application value in practical engineering.
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