Influence of Rainfall Intensity and Slope on Runoff and Sediment Reduction Benefits of Fine Mesh Net on Construction Spoil Deposits

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Abstract: Fine mesh nets (FMNs) are commonly used as a mulch material to control soil erosion in construction spoil deposits. Here, three rainfall intensities (60–120 mm h⁻¹) and seven slope gradients (5–35°) were considered in relation to an FMN’s function of reducing soil erosion on spoil deposits. Soil surfaces covered with an FMN (NS) were prepared in 2 m × 0.5 m soil boxes, with a smooth surface (SS) as the control. Runoff and sediment reduction benefits (RRB and SRB, respectively) were used to quantify the role of the FMN in soil erosion reduction. The FMN performed better in controlling the total sediment yield (mean SRB: 35.9%) compared with total runoff (mean RRB: 5.3%). There was a difference in runoff between SS and NS under a low rainfall intensity (60 mm h⁻¹; p < 0.05). SS and NS on different slopes generated similar runoff, with significantly different sediment yields (p < 0.05). The benefits of the FMN basically decreased with increases in the rainfall intensity and slope, although the RRB fluctuated on different slopes. The results demonstrate that the soil and water conservation benefits of the FMN on spoil deposits were influenced by the rainfall intensity and slope. The effectiveness of FMNs in soil erosion control needs further investigation in the context of local climates.

Keywords: fine mesh net; spoil deposits; erosion control; slope; rainfall intensity

1. Introduction

Construction activities globally promote economic and social development while causing environmental problems, such as the formation of numerous spoils [1,2]. Spoil deposits, unique geomorphic units, are formed following surface excavations during construction projects [3–5]. Spoil deposits have become a major source of soil and water loss, owing to their associated loose material, bare surface, and poor erosion resistance characteristics [6–8]. In addition, such soil and water loss are severely harmful due to the random accumulation of abandoned soils and slags, coupled with frequent interference by human activities. Therefore, it is crucial to control soil erosion in spoil deposits formed during construction projects.

Rainfall is the primary force driving soil erosion, and rainfall intensity is a key factor influencing soil erosion development [9,10]. Nam et al. (2014) observed that the soil erosion rate was proportional to rainfall intensity, whereas Dong et al. (2012) reported that the surface runoff rate was positively correlated with rainfall intensity, based on an estimation of the erosion patterns of highway spoil deposits under field-simulated rainfall [11,12]. According to Zhang et al. (2018), when the rainfall intensity increased from 20 to 60 mm h⁻¹,
the onset time of surface runoff could be shortened by 11–20 s [13]. Therefore, from multiple perspectives, rainfall intensity plays an essential role in soil erosion under different environmental conditions [14,15]. In addition, slope is a key factor influencing soil erosion [16]. Foster and Martin (1971) showed that sediment flows decreased with a decrease in the slope under similar conditions of compacted soil bulk density [17]. Meanwhile, Berger et al. (2010) observed that total sediment erosion increased by >40% when the slope increased from 10% to 30% [9].

Both biological and engineering strategies have proven effective in addressing soil loss during soil erosion under different rainfall intensities and slopes [18,19]. However, biological and bioengineering strategies should be the first choice for addressing environmental problems [20]. For example, mature and extensive vegetation can effectively prevent soil erosion associated with rainfall events. Furthermore, temporary strategies should be considered in the early stages of plant growth to minimize risks of erosion [21,22]. Mulching is a temporary soil and water conservation strategy in construction projects. Mulching can eliminate 64.0–99.6% of the raindrop kinetic energy [23–26], thereby reducing rill erosion by nearly half [27]. Zheng et al. (1995) demonstrated that the total erosion on sloping farmlands was reduced by 31–55% following mulching [28], whereas the amount of erosion and sediment on spoil deposits was reduced by >79% under different rainfall intensities [29].

The soil and water conservation benefits of temporary strategies have been widely reported. However, owing to a dearth of empirical research, the benefits of mulching in reducing runoff and sediment on spoil deposits have largely been based on experiments conducted on sloping farmlands [30,31]. Notably, the soil structure of spoil deposits associated with construction activities is damaged and the soil composition is complex [32]. Consequently, the erodibility of slope surfaces on spoil deposits is distinct from that of sloping farmlands. In addition, rainfall intensity has a distinctive effect on the performance of mulch materials such as geotextiles in controlling soil erosion; however, few reports have explored the benefits of mulching under different rainfall intensities [33]. An enhancement of our understanding of how the rainfall intensity and slope jointly affect soil erosion on spoil deposits could facilitate the implementation of optimal mulching strategies for slope protection.

Fine mesh nets (FMNs) have been applied extensively in construction projects to strengthen the soil structure and can be used as a mulch material, as a temporary strategy of soil conservation [34]. Therefore, the aim of the present study was to investigate soil and water loss from spoil deposit slopes with an FMN, and to assess how the rainfall intensity and slope influence the role of the FMN in soil erosion under simulated rainfall conditions. The results of the present study could facilitate the prevention and control of soil erosion on spoil deposits, in addition to the formulation of appropriate temporary strategies for soil and water conservation during the implementation of construction projects.

2. Materials and Methods
2.1. Soil

The experimental soil was collected from a road construction project site in the Loess Plateau, northeastern China (34°16′48″ N, 108°4′27″ E). The study site is in a warm temperate monsoon semi-humid climate zone, with annual precipitation of 635.1–663.9 mm and a mean annual temperature of 12.9 °C. The experimental soil is classified as clay loam soil (USDA Taxonomy), which represents the major soil type in the study site. Soil particle size distribution was measured using a Mastersizer 2000 (Malvern Instruments Ltd., Worcestershire, UK), and the physicochemical properties of the soil are listed in Table 1.
Table 1. Basic physicochemical properties of the experimental soil from a road construction site.

| Soil Type | Particle Size Composition/% | Organic Matter (%) | Rock (%) | Ammonium-N (g/kg) | Nitrate-N (g/kg) | Available K (g/kg) |
|-----------|-----------------------------|-------------------|----------|------------------|-----------------|-------------------|
| Clay loam | Clay < 0.002 mm | Silt 0.002–0.05 mm | Sand > 0.05 mm | 5.14 | 85.01 | 9.85 | 7.3 | 0 | 36 | 4 | 60 |

2.2. Experimental Setup

Simulated rainfall experiments were performed in soil boxes made of steel plates, each measuring 2 m (length) × 1 m (width) × 0.45 m (depth). The soil boxes were separated into two plots using a steel plate, resulting in a final width of 0.5 m. Each soil box had a V-shaped outlet at its downslope end for collecting surface runoff and sediment samples during rainfall (Figure 1a). There were 10 screened 0.5 cm-diameter holes at the bottom of the box for draining the infiltration water. The slope of the box was adjusted using a hydraulic lifting rod, and a slope scale was used to measure the slope gradient.

Rainfall was simulated using a side-sprinkle rainfall simulator, as described by Zhao et al. (2013) [35]. The device was manufactured by the Institute of Soil and Water Conservation, Chinese Academy of Sciences (Yangling, China). The simulator consists of a water supply unit and two independent rainfall machines. The rain nozzle was located 6 m above the ground, with a 7 m distance between the independent rainfall machines (Figure 1b). The effective rainfall area was 5 m × 7 m, and the Christiansen coefficient of uniformity was approximately 90%, which is higher than the requirement (80%) for simulated rainfall experiments [36].

![Figure 1](image-url)
2.3. Preparation of Soil and Fine Mesh Net

Before being placed in soil boxes, the experimental soil was sifted through a 10 mm sieve and then air dried in the laboratory. Dry quartz sand (5 cm height) was laid at the bottom of the soil box. The bulk density of the subsoil (20–40 cm depth) was between 1.35 and 1.50 g/cm$^3$, whereas the bulk density of the topsoil (0–20 cm depth) was 1.05–1.10 g/cm$^3$, similar to that of natural spoil deposits (Figure 1c). The initial moisture contents of the subsoil and topsoil were approximately 10%. After each box was filled, the soil surface was smoothed using a wooden plate.

An FMN was used to cover the soil surface in the box (NS treatment; Figure 1c) and was kept in close contact with the topsoil during the experiment. The net was made of polyethylene with a small thickness (2 mm) and had a large open area percentage (60%; GB 5725-2009) [37]. A smooth surface with no FMN (SS treatment) was used as the control. The slopes of spoil deposits are mainly in the 25–40° range [38], although there are also temporary spoil deposits with slopes of <25° in linear construction projects. Therefore, the slope of the soil box was adjusted to 5°, 10°, 15°, and 20°, which represent gentle slopes, and 25°, 30°, and 35°, which represent steep slopes. Such slope gradients are common in construction project areas of the Loess Plateau.

2.4. Rainfall Simulation and Data Analysis

After soil and FMN preparation in the boxes, the runoff area was completely covered with a plastic sheeting, and the simulator was adjusted to initiate the rainfall simulation when the rainfall uniformity was >90%. Three rainfall intensities of 60, 90, and 120 mm h$^{-1}$ were applied over a duration of 60 min for each test [39]. When surface runoff began at the outlet of the soil box, runoff and sediment samples were continuously collected into 6 L buckets with known weights, and an empty bucket was switched every 1–3 min depending on the rainfall intensity. At rainfall termination, the buckets containing runoff and sediment samples were weighed. Subsequently, approximately 12 h was required to sink the solid fraction, and a clear supernatant was poured off on the following day. Afterward, the sediment samples were placed in iron basins and oven dried at 105 °C to constant weight. Dry sediment samples were weighed again to obtain the sediment yield; the runoff volume was obtained by subtracting the sediment yield from the sample weight. The accuracy of the electronic scale used for weighing was 0.01 g.

To compare the influence of the rainfall intensity and slope on the function of the FMN in soil erosion control, the runoff and sediment yields obtained during rainfall were calculated over 60 min durations from the start of rainfall. The benefits of the FMN in reducing soil and water losses were quantified using the runoff reduction benefit (RRB) and sediment reduction benefit (SRB), respectively, which are similar to the effectiveness index proposed by Sutherland (1998) [40]. The RRB and SRB of the FMN at different rainfall intensities and slope gradients were calculated using Equations (1) and (2), respectively [41]:

$$\text{RRB} (\%) = \left(\frac{M_0 - M_i}{M_0}\right) \times 100\% \quad (1)$$

$$\text{SRB} (\%) = \left(\frac{W_0 - W_i}{W_0}\right) \times 100\% \quad (2)$$

where $M_i$ and $M_0$ are the total runoff volumes from NS and SS during a rainfall event, respectively (L); $W_i$ and $W_0$ are the total sediment yields from NS and SS during a rainfall event, respectively (kg·m$^{-2}$). If the RRB or SRB is < 0, the FMN is not beneficial for controlling runoff or sediment loss; otherwise, there is a benefit from the FMN with regard to reducing soil erosion.

Each treatment had three replicates, and in each run, different surface patterns (SS and NS) were prepared as mentioned previously. All data analyses were performed in Excel v2016 (Microsoft Corp., Redmond, WA, USA) and IBM SPSS Statistics 23 (IBM Corp., Armonk, NY, USA). Prior to statistical analyses, the data were tested for normal
distribution, and non-normally distributed data were log-transformed or reciprocally transformed. Independent sample t-tests were used to determine significant differences in runoff and sediment yield between the SS and NS treatments \((p \leq 0.05)\). The general linear model was used to test for significant interaction effects of rainfall intensity and slope on runoff and sediment. Pairwise correlations among runoff, sediment, slope, rainfall intensity, and FMN mulching were analyzed using Pearson’s correlation coefficients, and Origin v2021b (OriginLab Corp., Northampton, MA, USA) was used to draw a graph and fit the correlation functions. Linear regression analysis was used to assess the correlation between runoff and slope, while logarithmic regression analysis was used to assess the correlation between sediment yield and slope. Furthermore, non-linear regression analysis was used to identify correlations among runoff, sediment yield, slope, and rainfall intensity.

3. Results

3.1. Sediment and Runoff Reduction Benefits of Fine Mesh Net

The descriptive statistics of the runoff volume and sediment yield after the rainfall simulation are summarized in Table 2. Under the experimental conditions, there was no significant difference in runoff volume between the treatments SS (range: 25.26–88.63 L) and NS (range: 16.18–92.25 L). However, sediment tended to be produced more easily under the SS treatment (range: 0.22–3.32 kg) than under the NS treatment (range: 0.16–2.31 kg; \(p < 0.01\)). Accordingly, the FMN reduced the sediment yield significantly, with a mean SRB of 35.93%. The effects on runoff volume were not considerable, with a mean RRB of 5.26%. Based on the coefficients of variation (CVs), both runoff volume and sediment yield were moderately variable (10% < CV < 100%); however, the CV values of the sediment yield were nearly twice those of the runoff volume.

Table 2. Descriptive statistics of slope runoff and eroded sediment under simulated rainfall events for 60 min.

| Item             | Treatment | Maximum | Minimum | Mean  | Standard Deviation | Coefficient of Variation (%) |
|------------------|-----------|---------|---------|-------|--------------------|-------------------------------|
| Runoff volume (L)| SS        | 88.63   | 25.26   | 60.85 | 20.47              | 33.64                         |
|                  | NS        | 92.25   | 16.18   | 57.65 | 23.03              | 39.95                         |
| Sediment yield (kg)| SS    | 3.32    | 0.22    | 1.67  | 1.02               | 61.08                         |
|                  | NS        | 2.31    | 0.16    | 1.07  | 0.74               | 69.16                         |
| RRB (%)          | -         | 22.99   | 0.41    | 5.26  | 8.04               | 91.47                         |
| SRB (%)          | -         | 59.16   | 16.67   | 35.93 | 12.06              | 31.90                         |

SS, smooth surface (control); NS, soil surface covered with a fine mesh net (the same notation is used hereinafter); RRB, runoff reduction benefit; SRB, sediment reduction benefit.

3.2. The Role of Fine Mesh Net in Relation to Slope Gradient

3.2.1. Relationship between Slope and Runoff

There was no significant difference in the runoff volume between the SS and NS treatments on any of the slopes tested (Table 3). Runoff was significantly linearly negatively correlated with the slope under different rainfall intensities \((p < 0.05)\), with a minimum coefficient of determination \((R^2)\) of 0.72 (Figure 2). A higher correlation between the runoff and slope was observed under the NS treatment than under the SS treatment. Under a rainfall intensity of 60 mm·h⁻¹, an increase in the gentle slope from 5° to 20° (by 300%) resulted in only 12.2% (NS) and 6.9% (SS) decreases in runoff. However, when the steep slope was increased from 25° to 35°, the runoff decreased sharply, by 37.1% (NS) and 25.3% (SS), suggesting that the effect of the slope on runoff was associated with the FMN. Under a rainfall intensity of 90 mm·h⁻¹, runoff decreased by 20.50 L (NS) and 13.16 L (SS) with an increase in the slope from 5° to 35°, which were 1.68 and 1.04 times the runoff reduction under the rainfall intensity of 60 mm·h⁻¹, respectively. The slope could explain 95% (NS) and 89% (SS) of runoff. Under a rainfall intensity of 120 mm·h⁻¹, runoff exhibited similar decreasing trends, with an increase in the slope gradient, when compared to the
observations under rainfall intensities of 60 and 90 mm·h−1. With an increase in the slope, although the runoff decreased, the RRB fluctuated under different rainfall intensities.

Table 3. Independent sample t-tests for the difference in runoff volume and sediment yield between soil surface treatments with (NS) and without a fine mesh net (SS) on different slopes (n = 2).

| Slope Gradient | Runoff Volume | Sediment Yield |
|----------------|---------------|----------------|
|                | F  | p   | F  | p   |
| 5°             | 0.01 | 0.98 | 4.95 | 0.03 |
| 10°            | 0.15 | 0.90 | 9.60 | 0.00 |
| 15°            | 0.25 | 0.62 | 27.45 | 0.00 |
| 20°            | 0.14 | 0.71 | 19.89 | 0.00 |
| 25°            | 0.29 | 0.59 | 18.13 | 0.00 |
| 30°            | 0.01 | 0.95 | 12.27 | 0.01 |
| 35°            | 1.40 | 0.24 | 5.83  | 0.02 |

Note: probabilities considered statistically significant are indicated in bold font (p < 0.05).

Figure 2. Relationship between runoff and slope under different treatments. The combinations of numbers (60, 90, and 120) and letters (NS (surface covered with a fine mesh net) and SS (smooth surface)) represent the soil surface treatments under rainfall intensities of 60, 90, and 120 mm·h−1 (similar notation is used hereafter). The inset shows the runoff coefficients of the SS (white) and NS (black) treatments on seven different slopes (5°, 10°, 15°, 20°, 25°, 30°, and 35°).

3.2.2. Relationship between Slope and Sediment

There was a significant difference in the sediment yield between the SS and NS treatments on each slope tested (p < 0.05; Table 3). Compared to SS, NS significantly reduced the sediment yield on different slopes (p < 0.01). The greater the slope, the larger the relative difference in sediment yield between the two treatments (Figure 3), which indicated that the SRB of the FMN decreased with an increase in the slope. Under different rainfall intensities, the relationship between the sediment yield and slope could be described based on a logarithmic function for both the SS and NS treatments; that is, the sediment yield increased significantly with an increase in the slope (p < 0.01), with R² values of 0.69 (SS) and 0.66 (NS) under a rainfall intensity of 60 mm·h−1, and >0.90 under higher rainfall intensities. In general, the sediment yield leveled off progressively with an increase in the slope.
was increased further to 120 mm (SS); the SRB accounted for 71.4% of that under a rainfall intensity of 60 mm. The increases in total sediment yields during the observation period.

Notably, the SRB of the FMN decreased under higher rainfall intensities, despite the increased rainfall intensity. At a rainfall intensity of 60 mm, the runoffs of the NS and SS treatments increased by 16.36 and 16.26 L, respectively; there was no considerable change in the RRB, which was equivalent to 75% of that under a rainfall intensity of 60 mm. When the rainfall intensity was increased from 60 to 90 mm, the runoffs in the NS and SS treatments increased by 30.97 and 35.04 L, whereas the SRB observed was the smallest. Notably, the SRB of the FMN decreased under higher rainfall intensities, despite the increases in total sediment yields during the observation period.

Figure 3. Relationship between sediment yield and slope under different treatments. The inset represents sediment yields per unit area in the SS (smooth surface/white) and NS (covered with a fine mesh net/black) treatments on seven different slopes (5°, 10°, 15°, 20°, 25°, 30°, and 35°).

3.3. Fine Mesh Net Function in Relation to Rainfall Intensity

3.3.1. Relationship between Rainfall Intensity and Runoff

To reveal the effect of the FMN on runoff under different rainfall intensities, the mean runoff volume on different slopes (5–35°) was plotted for the SS and NS treatments separately (Figure 4A). In both cases, the mean runoff increased with an increase in the rainfall intensity, and the difference between the SS and NS treatments was significant under a rainfall intensity of 60 mm-h⁻¹ (p < 0.05). The results indicate that the FMN had a prominent effect on reducing the runoff volume at a low rainfall intensity; however, the effect was limited under higher rainfall intensities. Under a rainfall intensity of 60 mm-h⁻¹, the runoffs in the NS and SS treatments were remarkably different, with means of 29.02 and 34.78 L, respectively; the RRB was 16.6%. When the rainfall intensity was increased from 60 to 90 mm-h⁻¹, the runoffs in the NS and SS treatments increased by 30.97 and 35.04 L, respectively; the RRB was only 2.6%, which was 0.15 times that under a rainfall intensity of 60 mm-h⁻¹. When the rainfall intensity was further increased from 90 to 120 mm-h⁻¹, the runoffs of the NS and SS treatments increased by 16.36 and 16.26 L, respectively; there was no considerable change in the RRB, which was equivalent to 75% of that under a rainfall intensity of 90 mm-h⁻¹.

3.3.2. Relationship between Rainfall Intensity and Sediment

The effect of the FMN on the sediment yield under different rainfall intensities is shown in Figure 4B, based on the mean sediment yields on the seven slopes. The mean sediment yields in both the SS and NS treatments increased significantly with an increase in the rainfall intensity (p < 0.01), and higher sediment yields were observed in the SS treatment than in the NS treatment under different rainfall intensities (p < 0.01). At a rainfall intensity of 60 mm-h⁻¹, the sediment yield of the SS treatment was 1.99 times that of the NS treatment, with a large SRB, at 50.0%. When the rainfall intensity was increased from 60 to 90 mm-h⁻¹, the sediment yield increased by 0.88 kg (NS) and 1.21 kg (SS); the SRB accounted for 71.4% of that under a rainfall intensity of 60 mm-h⁻¹. The sediment yields of SS and NS exhibited the greatest difference when the rainfall intensity was increased further to 120 mm-h⁻¹, which were 0.64 and 0.89 times those under rainfall intensities of 60 mm-h⁻¹ and 90 mm-h⁻¹, respectively, whereas the SRB observed was the smallest. Notably, the SRB of the FMN decreased under higher rainfall intensities, despite the increases in total sediment yields during the observation period.
Figure 4. Runoff and sediment yields from soil surfaces covered with a fine mesh net (NS) and without a fine mesh net (SS) under different rainfall intensities (60, 90, and 120 mm·h⁻¹). Different lowercase letters above the error bars indicate significant differences between the NS and SS treatments (The significant difference of subfigure (A) at 0.05 level; The significant difference of subfigure (B) at 0.01 level).

3.4. Comprehensive Analysis of Factors Influencing Soil Erosion

Pearson’s correlations among rainfall intensity, slope, FMN mulching, sediment yield, and runoff are shown in Figure 5. Runoff was significantly positively correlated with rainfall intensity ($R^2 = 0.59; p < 0.01$) and negatively correlated with slope ($R^2 = -0.28; p < 0.05$). In addition, sediment yield was significantly positively correlated with slope, rainfall intensity, and runoff ($R^2 = 0.57, 0.59, and 0.45$, respectively; $p < 0.01$). Furthermore, the slope and rainfall intensity had significant interaction effects on the sediment yield ($p < 0.05$). The FMN could significantly reduce the sediment yield ($p < 0.01$) but had no significant effect on runoff.

Multiple regression analysis of runoff (or sediment yield) with slope, rainfall intensity, and sediment yield (or runoff) was conducted using a non-linear model (Table 4). The $F$ values of the regression models for the runoff and sediment yields under the NS and SS treatments were all greater than 40.00 ($p < 0.01$). The results indicate that the comprehensive influence of the rainfall intensity and slope on runoff and sediment yields could be accurately described based on a non-linear function ($R^2 > 0.75$).
Correlation
1.0
0.8
0.6
0.4
0.2
0
− 0.2
− 0.4
− 0.6
− 0.8
− 1.0

Figure 5. Pearson’s correlations among runoff, sediment yield, rainfall intensity, slope, and fine mesh net cover treatment. S = slope; C = FMN cover; I = rainfall intensity; M = runoff; W = sediment yield; *, p < 0.05; **, p < 0.01.

| Variable | Treatment | W(M) = a· S + b·I + c·M(W) + d |
|----------|-----------|----------------------------------|
|          |           | a   ± b   | c   ± d   | F    | R^2 | p    |
| W        | NS        | 0.06 ± 0.01 | 0.01 ± 0.01 | 0.02 ± 0.01 | −1.89 ± 0.30 | 44.28 | 0.78 | 0.00 |
| M        | SS        | 0.11 ± 0.01 | −0.02 ± 0.02 | 0.07 ± 0.02 | −2.47 ± 0.39 | 50.97 | 0.80 | 0.00 |
| W        | SS        | −0.80 ± 0.15 | 0.79 ± 0.06 | 2.52 ± 2.16 | −1.38 ± 5.81 | 190.37 | 0.94 | 0.00 |
| M        | SS        | −0.86 ± 0.11 | 0.68 ± 0.05 | 4.01 ± 1.10 | 10.21 ± 4.07 | 276.68 | 0.96 | 0.00 |

4.1. Influence of Rainfall Intensity on Soil Erosion

The runoff and sediment yield on slopes are key factors used to characterize the severity of soil erosion. Our results show that the runoff and sediment yield on slopes covered with and without an FMN increased with an increase in the rainfall intensity (Figure 4). A similar conclusion was made by Kumar and Midha (2017) after testing the erosion control performance of coir and jute-based geomeshes [42]. In addition, according to Sheng et al. (2016), rainfall erosivity and runoff erosivity of slope rainfall were enhanced with an increase in the rainfall intensity, which increased the magnitude of soil loss and runoff [16]. This is mainly due to surface runoff being influenced jointly by the rainfall intensity and infiltration rate. In addition, rainfall intensity influences the soil infiltration rate.

In the early stages of rainfall, the greater the rainfall intensity, the higher the initial infiltration rate. When surface runoff occurs, the infiltration rate decreases rapidly with an increase in the rainfall intensity and finally tends to stabilize. The stable infiltration rate under a heavy rainfall intensity is slightly lower than that under a low rainfall intensity [43]. The runoff and sediment yield of the current experiments were acquired during rainfall events, and the total infiltration amount decreased with an increase in the rainfall intensity. Therefore, the total runoff was mainly influenced by the rainfall intensity. Within the same rainfall duration, the slope runoff increased with an increase in the rainfall intensity. As a sediment transport medium, runoff has a greater scouring effect on the soil under a higher rainfall intensity. In addition, the kinetic energy of raindrops is greater under a higher rainfall intensity [44,45], which further accelerates the damage to the soil and provides a rich source of loose materials for runoff transportation, in turn promoting the erosion process.

Table 4. Compound equation of runoff (M), sediment yield (W/Kg), rainfall intensity (I/mm h^{-1}), and slope (S/°) on slope surfaces covered with a fine mesh net (NS) and smooth surfaces (SS).
4.2. Influence of Slope on Soil Erosion

With an increase in the slope, the total sediment yield on slopes covered with and without an FMN increased first and then leveled off progressively, under the same rainfall intensity, which was opposite to the trend of runoff. The results are consistent with the soil erosion characteristics observed in farmland [46]. Li et al. (2014) investigated the erosion process on black soil slopes and showed that with the increase in the slope from 5° to 10°, the sediment yields increased by 0.4–0.9 times [47]. As the slope increases, the soil is subjected to a greater component force of gravity along the slope, resulting in lower soil stability [48], and it is more likely to be migrated under the action of raindrop splash erosion and runoff. Conversely, as the length of the soil box is the same, the area receiving rainfall decreases with an increase in the slope. As a result, the runoff decreases on steeper slopes, and the runoff carrying capacity exhibits a decreasing trend with an increasing slope [49].

The slope and rainfall per unit area mutually varied under the same rainfall intensity in the present study; however, sediment yield per unit area and total sediment yield had similar trends under a similar rainfall intensity (Figure 3). The results indicate that the erosion of specific units with loose soil surfaces, such as spoil deposits, could be predominately influenced by the rainfall intensity. Indeed, the correlation analysis results show that the rainfall intensity explained the sediment yield better than the slope. Furthermore, runoff is mainly influenced by soil infiltration performance and rainfall intensity, while no consistent conclusion has been reached on the quantitative relationship between slope differences and soil infiltration characteristics [50].

A previous study on infiltration performance in a clay loam soil showed that the slope had no significant effect on the soil infiltration rate and cumulative soil infiltration [51]. However, in the present study, under the same rainfall duration and intensity, the area receiving rainfall was smaller at the same slope length. Consequently, the total runoff decreased with an increase in the slope under the same rainfall intensity owing to the combined action of other factors (slope and area receiving rainfall). Guo et al. (2019) reached a similar conclusion for the change in runoff on iron tailing sand slopes under a 60 mm·h⁻¹ rainfall intensity [52]. This phenomenon was also observed by Wang et al. (1998), who investigated soil erosion on different slope lands in the Loess Plateau in Suide, Shaanxi Province, China [53].

Based on the properties of spoil deposits, the received rainfall amount of the slope was correlated positively with runoff and negatively with sediment yield (p < 0.05 or 0.01; Table 5). The results of the correlation analysis also explain that runoff decreased with the increase in the slope, but the sediment yield increased simultaneously. The findings indicate that the received rainfall amount was effective for slope erosion. However, the relationship between the slope and runoff is complex, because different types of soil have distinctive physical properties, such as soil structure, infiltration capacity, and erosion resistance [54]. Therefore, the runoff patterns of other spoil deposit types still need to be further studied by taking into account soil physical properties.

4.3. Factors That Influence Runoff and Sediment Reduction Benefits of Fine Mesh Net

The RRB and SRB can describe the performance of an FMN in controlling runoff and sediment yields, respectively, which are critical for the determination of the erosion control benefits of mulching on slopes. In the present study, the RRB of the FMN decreased drastically with an increase in the rainfall intensity, ranging from 16.6% (60 mm·h⁻¹) to 1.9% (120 mm·h⁻¹; Figure 4A). The result indicates that the FMN does not guarantee runoff reduction benefits but could decrease runoff during low-intensity rainfall events. The FMN is manufactured using a polyethylene material characterized by loose voids and high water permeability. In addition, the polyethylene material has low hygroscopicity and poor water-holding capacity [55,56]. Consequently, the FMN has a poor runoff reduction effect, with a low RRB. Furthermore, due to the close contact between the FMN and the soil, the FMN texture can hinder the transport of runoff on gentle slopes under a low rainfall
intensity, altering the initial runoff process and prolonging the runoff time. Therefore, in the absence of the FMN, soil infiltration increased in the early stages, and this stagnation effect was weak under heavy and moderate rainfall intensities. Similar results were obtained with coir geotextiles by Sutherland and Ziegler (2007) [57]. The findings explain why the RRB of the FMN was lower under higher rainfall intensities in the present study.

Table 5. Correlation coefficients among the received rainfall amount of soil boxes, runoff, and sediment yield under different rainfall intensities.

|   | P1      | P2      | P3      | W1      | W2      | W3      | M1      | M2      | M3      |
|---|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| P1| 1       | 1.000 **| -0.443 *| -0.812 **| -0.739 **| 0.776 **| 0.850 **| 0.858 **|         |
| P2| 1       | 1.000 **| -0.443 *| -0.812 **| -0.739 **| 0.776 **| 0.850 **| 0.858 **|         |
| P3| 1       | 1       | 0.806 **| 0.692 **| 0.086   | -0.291  | -0.162  |         |         |
| W1| 1       | 0.827 **| -0.429 *| -0.659 **| -0.585 **|         |         |         |         |
| W2| 1       | 0.432 * | -0.703 **|         |         |         |         |         |         |
| W3| 1       | 0.786 **| 0.794 **|         |         |         |         |         |         |
| M1| 1       | 0.771 **|         |         |         |         |         |         |         |
| M2| 1       |         |         |         |         |         |         |         |         |
| M3|         |         |         |         |         |         |         |         |         |

Note: P1, P2, and P3 are the received rainfall amount under rainfall intensities of 60, 90, and 120 mm·h⁻¹, respectively; W1, W2, and W3 are the runoff under rainfall intensities of 60, 90, and 120 mm·h⁻¹, respectively; M1, M2, and M3 are the sediment yield under rainfall intensities of 60, 90, and 120 mm·h⁻¹, respectively. *, p < 0.05; **, p < 0.01 (two-sided test).

Conversely, the FMN had a prominent effect on the sediment yield reduction. The SRB of the FMN reached a maximum of 50.0% under a rainfall intensity of 60 mm·h⁻¹, which was higher than the 31.9% under a rainfall intensity of 120 mm·h⁻¹ (Figure 4B). When the soil surface is covered with an FMN, raindrops hit the mulching material, which interrupts the process of free fall; consequently, large raindrops are dispersed after contact with the FMN, and the kinetic energy of raindrops is attenuated. The FMN not only prevents the direct contact of the raindrops with the soil but also buffers the splash erosion of the soil, thereby reducing the sediment yield during a rainfall event. Meanwhile, the contact area between the FMN and the soil is equal under different rainfall intensities, and there is no major difference in the amount of sediment that can be adsorbed in a single rainfall event; nevertheless, sediment yields under heavy rainfall intensities are greater than those under low rainfall intensities [58]. Therefore, compared to under moderate and high rainfall intensities, the FMN plays a more prominent role in soil erosion control on gentle slopes under low rainfall intensities, leading to a high SRB.

Our findings are largely consistent with the results of Liu et al. (2017) obtained through rainfall simulation experiments [29]. In the previous study, the runoff and sediment reductions of a gauze net were basically equivalent on exposed slopes in a spoil deposit area; however, there was a difference in the capacity of the gauze net to control the runoff and sediment yield compared to that of the FMN. This is mainly due to the following reasons: (1) In the previous study, a 1 × 1 mm gauze net was placed 10 cm from the soil surface. Compared to the raindrops with the same diameter falling from a height of 7.5 m, the gauze net weakened the force of the raindrops on the soil, which could slow down surface crust formation and, in turn, promote soil infiltration. In addition, the gauze net is dense, and little water penetrates during the rainfall process, which greatly reduces the kinetic energy of the raindrops [59]. (2) Owing to the difference in experimental design, the soil erodibility (0.0064 t·hm⁻²·h·(hm⁻²·MJ·mm)⁻¹) in the previous study by Liu et al. (2017) was lower compared to the soil erodibility in the present study (0.0158 t·hm⁻²·h·(hm⁻²·MJ·mm)⁻¹) [60]. The stronger the erosion resistance of a soil, the less soil erosion occurs under rainfall [61].

5. Conclusions

Our experimental results demonstrate that the rainfall intensity and slope could influence soil erosion on spoil deposits in a construction project area. Overall, the sediment
loss of the mulching treatment (soil surface covered with an FMN) was lower than that of the control treatment (smooth surface), which was not the case for runoff. Specifically, there was a significant difference in runoff between the two treatments only under a low rainfall intensity (60 mm·h⁻¹), whereas the difference in the sediment yield between treatments was significant in all cases with different rainfall intensities (60–120 mm·h⁻¹). In addition, there was no significant difference in runoff between the two treatments from gentle to steep slopes (5–35°), whereas the sediment yields of soil surfaces covered with the FMN were markedly lower than those of smooth surfaces.

The findings suggest that the rainfall intensity and slope gradient are two major factors influencing the soil and water conservation benefits of FMNs on spoil deposits. The positive roles of FMNs in soil erosion control depend on local rainfall characteristics in construction project areas. Hence, rainfall conditions in the project area where FMN mulching is used should be taken into account. For example, if the rainfall intensity is >90 mm·h⁻¹ in a single rainfall event, FMN mulching is not effective for water conservation. However, considering its soil conservation benefits under different slopes and rainfall intensities, FMN mulching is still recommended based on a soil conservation perspective.

In the present study, we assessed the effectiveness of an FMN in the control of soil and water loss on spoil deposits under different rainfall intensities and slopes. The effects of the FMN in terms of the SRB were significant. Nevertheless, our experimental design adopted soil boxes under laboratory conditions, and the results should be verified at the field scale under natural conditions in future. The results of this study could provide a reference for the formulation of slope protection strategies and support comprehensive evaluation of the benefits of mulching under an FMN.

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