1. Motivation and objectives

Soil surface coverage has a significant impact on water infiltration, runoff, and soil erosion yields. In particular, surface stones protect the soil from raindrop detachment, thereby reducing the overall flow and preventing the sediment transport capacity, and thus, they prevent sealing the soil surface, increasing the infiltration rate.

Owing to the different inter-related processes, there is ambiguity concerning the quantitative effect of stones, and process-based understanding is limited. For instance, nothing is known about the effects of surface stones on individual sediment size classes, and the extend to which erosion of stone-protected soils is controlled by rainfall characteristics and the initial soil moisture content.

The objectives of this study were to:

(i) Quantify how stone features affect the hydrological response and eroded sediment yields

(ii) Understand the local effect of isolated surface stones, that is, the changes of the soil particle size distribution in the vicinity of a stone

(iii) Model the observed data using a physics-based soil erosion model

2. Design of experiment

Flume Size: 6-m long, 2-m wide, divided into 2 × 1-m wide flumes
Soil: 4% clay, 29% silt, 41% sand, 26% fine gravel
Slope: 2.2%

Preparation: The 0.2 m of the soil surface was re-ploughed and any gravel (> 2 cm) removed. Then, the soil surface was smoothed using a mechanical scraping device in order to ensure the same initial roughness and uniform slope

Rainfall simulator: 10 Veejet nozzles mounted 3-m above the soil surface, rainfall intensity controlled by oscillation frequency (1)

Experiments: Experiments using the EPFL 6-m × 2-m erosion flume were conducted at different rainfall intensities and stone coverage (see Table 1 for more details). The total sediment concentration, the concentration of the individual size classes and the flow discharge were measured

3. Model

Stones reduce the average cross sectional area and provide additional protection to the original soil. The Hairsine-Rose (H-R) mechanistic erosion model [2, 3] was modified to account for the reduction in exposed area:

\[
\frac{dh}{dt} \frac{da}{dx} = R
\]

where \( h = 1 - C \)

Notation:
- \( n \): proportion of the cross-sectional area not covered by stones
- \( h \): water depth (m)
- \( a \): unit discharge (m² s⁻¹)
- \( w \): rainfall intensity (mm h⁻¹)
- \( c \): class sediment concentration (kg m⁻³)
- \( e_a \): rainfall detachment (kg m² s⁻¹)
- \( e_r \): rainfall redetachment (kg m² s⁻¹)
- \( m \): mass of deposited class i sediment per unit area (kg m⁻²)
- \( C_i \): stones coverage (%)

5. Discussion and Conclusions

A. On well controlled laboratory conditions

- Soil erosion is proportional to the soil surface area exposed to raindrops and effective rainfall (Figs. A-1-3)
- The relationship between soil erosion and area exposed is controlled by a smaller extent by the soil's initial moisture content and bulk density (Fig. A-3)

The H-R model could reproduce well the measured sediment concentrations when a high rainfall intensity and low stone cover were used (Fig. 5). However, the modified H-R model could not reproduce the details of measured sediment breakthrough curves for conditions of low rainfall intensity and high stone cover.

B. The selective effect of stones

Stones were found to affect selectively the different size classes in a manner that was consistent with these time scales

- For short times (the period before the shield layer development), the stone cover reduced erosion of the finer particles (< 2 and 2-20 µm)
- For the mid-size classes (20-50 and 50-100 µm), the protection decreased, while erosion of the larger size classes (100-315 and 315-1000 µm) was unaffected

- At long times (after the peak concentration), the stone cover decreased the concentration of the individual size classes in proportion to effective precipitation and area exposed to raindrops

4. Results

Table 1: Summary of the laboratory flumes experiments

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Precipitation (mm/h)</th>
<th>Bulk density (g cm⁻³)</th>
<th>Sediment concentration (%)</th>
<th>Discharge rate (m³ min⁻¹)</th>
<th>Sediment rate (g min⁻¹)</th>
<th>Time-to-runoff (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H6</td>
<td>Rare</td>
<td>6.81</td>
<td>13.5</td>
<td>60</td>
<td>5.0</td>
<td>6.69</td>
</tr>
<tr>
<td>H7-E1</td>
<td>Stones (30%)</td>
<td>7.58</td>
<td>22.7</td>
<td>25.4</td>
<td>15.2</td>
<td>6.89</td>
</tr>
<tr>
<td>H7-E2</td>
<td>Stones (40%)</td>
<td>8.26</td>
<td>30.6</td>
<td>14.5</td>
<td>13.5</td>
<td>6.91</td>
</tr>
<tr>
<td>H7-E3</td>
<td>Stones (60%)</td>
<td>9.13</td>
<td>36.7</td>
<td>19.7</td>
<td>13.5</td>
<td>6.69</td>
</tr>
</tbody>
</table>

4.1. Discussion

The modified H-R soil erosion model could predict sediment breakthrough curves of the individual size classes, except the two largest classes (315-1000 and > 1000 µm) which showed considerable scatter.

6. References


Acknowledgements

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