Experimental Investigation of Rainfall Induced Soil Erosion

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Introduction

It is widely recognized that rainfall induced soil erosion is a serious global problem with significant financial and environmental consequences. Soil erosion is particularly important in agricultural lands, where it results in a reduction of the cultivable soil depth and fertility. In addition, the problem of sedimentation on riverbeds and drainage networks, which reduces their capacity, increases flooding risk, blocks irrigation canals and shortens the design life of water reservoirs. Soil erosion is a two-phase process consisting of the detachment of individual soil particles from the soil mass and their transport by erosive agents such as running water and wind. Finding an analytical solution to soil erosion problems is impossible; therefore most studies are mainly based on laboratory experiments and the field investigations. The main objective of this research was to carry out an experimentally investigate the rainfall driven erosion process and to develop a functional relationship to quantify soil erosion rates.

Experimental set-up and procedure

Based on preliminary tests carried out in the field to find out actual characteristics of natural rainfall, a laboratory-scale rainfall simulator was designed and fabricated using perforated PVC pipes and a nozzle as shown in Figure 1. To generate raindrop distribution similar to natural rain, a frame mounted with the perforated pipes and the nozzle was moved back and forth with a span of about 10 cm using a wiper motor. The height of the moving set-up above the ground level was determined after carrying out several preliminary tests. The drop size distribution was tested using a tray filled with flour, which was briefly exposed to a rain and covered it back within a fraction of a second. The number of drops with different diameters was then counted. The drop size distribution simulated by the rainfall simulator is compared with actual rain in Figure 2. A soil bed with dimensions 600 x 600 x 100 mm was used for the tests, which consists of 70 mm thick soil sample placed on a layer of 30 mm thick porous bed to remove infiltrated water. The experimental set-up is as shown in Figure 3. The soil erosion rates were measured for five different soil bed slopes, four different soil types and four different simulated rainfall intensities.

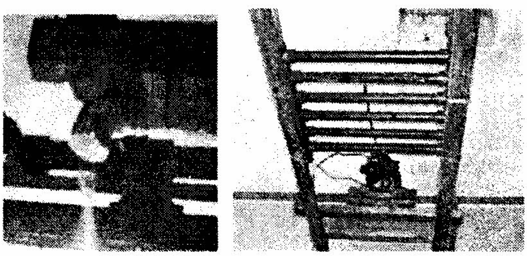

Figure 1. Two types of arrangements used to set-up the rainfall simulator

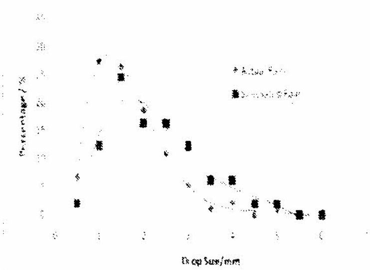

Figure 2. Comparison of drop size distribution generated by the rain simulator with a typical rain

Results and discussion

The soil erosion rate (q) depends on many parameters, such as rainfall intensity (I), mean diameter of raindrops (d_r), mean diameter of soil particles (d_s), dry density of soil (ρ), bed slope (S), acceleration of gravity (g), impact velocity of rain drops (V), soil characteristics (K), support factor to represent any erosion control measures (Po). The above parameters can be correlated by an equation of the form;

$$f(I, d_r, d_s, \rho, S, g, P, K, P_0, q) = 0 \ldots \qquad (1)$$

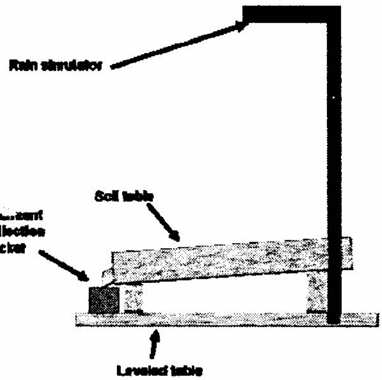

Figure 3. Experimental set-up

A few of the listed parameters, which were kept as constants during the experiments, can be excluded from the analyses. The raindrop velocity was not taken into account here as it is difficult to measure and control during the tests. The clay content (c) was taken as the soil characteristic in the experiments. Hence, the Eq. (1) simplifies to:;

$$f(I, d_r, d_s, \rho, S, g, c, q) = 0 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The following non-dimensional groups were derived using non-dimensional analysis.

$$X_1 = S\ ;\ X_5 = c\ ;\ X_3 = \frac{d_r}{d_s}\ ;\ X_4 = \frac{g d_s}{I^2}$$

$$X_5 = c \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

No direct correlation was found among the above groups. However, the non-dimensional groups, X_6 and X_7 derived below appear to showed a reasonable correlation.

$$X_6 = X_2.X_3.X_5\ ; \qquad X_7 = \frac{X_4}{X_1^2} \ldots\ldots\ldots\ldots (4)$$

The variation of X_7 with X_6 is shown in Figure 4. Although the data points show a significant scatter, a clear trend a clear trend is noticeable. Using this relationship, a new equation to calculate the rate of soil erosion was derived.

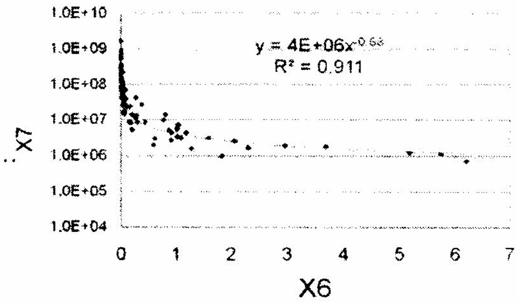

Figure 4. Variation of X_7 Vs X_6

$$q = 4.4E9\left[\frac{d_s g}{S^2 I^2}\right]^{-1.46}\left[\frac{I \rho d_s}{d_r c}\right]$$

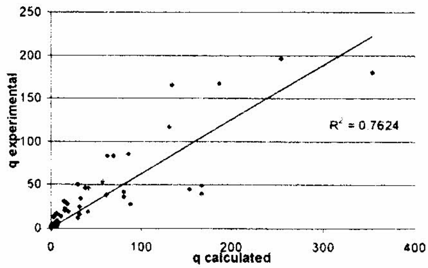

Figure 5. Comparison of erosion rates measured with that of computed values

The comparison of erosion rates computed using the above equation is compared with the experimental values in Figure 5. The deviation of results from the actual could be partly attributed to the factors that are difficult to control during the tests such as, initial moisture content and compaction of soil layers.

Conclusions

Based on the extensive laboratory experiments, a new equation was proposed to estimate rainfall induced soil erosion. The equation derived here can only be applicable for clayey soils without plant cover. However, to verify the applicability of this equation, more experiments are needed with additional parameters used such as, soil types, bed slopes and rainfall intensities. Also, the effect of other parameters on soil erosion, which were not considered in this study, should also be studied. In addition, the proposed equation needs to be tested using field data.