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The Effect of Soil Surface Slope on Splash Distribution under Water Drop Impact

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Abstract**—**The effects of down slope steepness on soil splash distribution under a water drop impact have been investigated in this study. The equipment used are the burette to simulate a water drop, a splash cup filled with sandy soil which forms the source area and a splash board to collect the ejected particles. The results found in this study have shown that the apparent mass increased with increasing downslope angle following a linear regression equation with high coefficient of determination. In the same way, the radial soil splash distribution over the distance has been analyzed statistically, and an exponential function was the best fit of the relationship for the different slope angles. The curves and the regressions equations validate the well known FSDF and extend the theory of Van Dijk.

Keywords**—**Splash distribution, water drop, slope steepness, soil detachment.

I. Introduction

THE influence of slope angle on soil detachment is of importance in soil conservation. This parameter has been investigated, in the laboratory and in the field, by many researchers, using different equipment and methods and under different conditions; the results found show wide variations.

The slope factor is one of the factors governing soil erosion. It represents the third important element in the U.S.L.E.. Theoretically, on a flat surface, the displacement of particles by splash is uniformly distributed. On any slope, raindrop impact ejects soil particles in upslope and downslope directions. The disparity increases as the slope steepness increases.

The splash distribution was investigated using circular splash boards ([6], [2]-[3]) and rectangular splash boards ([8], [9]). The particles distributed on the distance followed an exponential function ([7], [10], [2]-[3]).

The aim of this work is:

i) To measure the apparent mass, which is the total mass deposited in the compartments of the splash board divided by the source area and the drop number.
ii) Fit the best regression equation to the distribution of the particles over the radial distance.
iii) Validate the FSDF to the data of this study.

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II. Equipment and Experimental Procedures

A. Splash Board

This device is made to assess the weight of the detached soil particles distributed over the surface. This splash board is similar to that described by [7]. The splash board is made from the hard plastic and painted in white colour to ease observing the splashed particles and to allow easy and complete washing out of the soil particles splashed in.

Fig. 1 The splash board

B. Single Water Drops

Fig. 2 The water tub, the burette and the capillary tub

The equivalent drop diameter of water used is 4 mm with a velocity of 8.56 m/s ([1]). The fall height of this drop was 8 meters because, at this height, the drop velocity attains 95% of the natural raindrop velocity ([1]).

For each test, a volume of 20 ml of an approximate constant temperature (20°C) was used as did [7].

C. *Soil Distribution Measurements*

A splash cup, filled with soil, was placed in the centre of the splash board. The source area of 50.24 cm^2 was chosen, in such a way that all the drops fall onto the splash cup area (the area was selected after being tested before using the soil). The top of the splash cup was level with the first rim of the splash board. The water drops were released freely by opening the burette tape at a constant position to keep the same frequency.

Fig. 3 The oven

After each test, the splashed particles were flushed from the splash board compartments with a wash bottle and the particles filtered and dried in the oven for 24 hours.

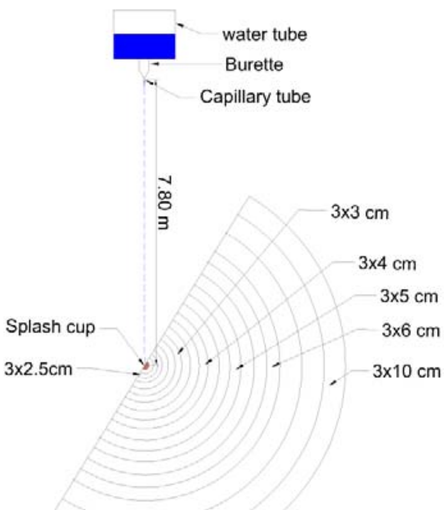

Fig. 4 General view of the splash board

Five samples were used to run one experiment and this experiment was repeated six times, which means thirty replications were used to represent the mean value.

The soil used is an agricultural sandy soil. The soil was cleaned from the roots and stones to have a homogeneous structure. The texture is 19.14% fine sand, 6.39% fine silt, 5.18% gross silt, 62.08% gross sand and 7.21% clay.

The slope angles used are as follows: 0°, 2°, 5°, 10°, 17° and 20° varied using the threaded rods. The different masses were calculated using the following expressions.

The mass of splashed particles collected in the compartments m_i (l_i) ($g/m^2/mm$) ([2]) is, in this study, not divided by the millimeter of rainfall but by the drop number.

$$m_i = \frac{M_i}{\pi \cdot l_i \cdot w_i} / drop \tag{1}$$

m_i is the mass normalized per unit of compartment and per water drop,

M_i in (g) is the mass collected in the ring i,

li (m) is the radial distance from the center of the source to the center of the ring i,

w_i in (m) is the width of the ring i.

The apparent mass Mapp (in g/m²/drop) of the particles detached, from the soil source and splashed on the splashboard is calculated by the following formula according to [5]:

$$M_{app} = \frac{\sum M_i}{A_{cup} \cdot N_{drop}} \tag{2}$$

M_i in (g) is the mass deposited in the rings of the splashboard,

A_{cup} (m²) is the surface of the soil cup and n is the number of drops.

m(r) is the mass per unit source area, per unit target area, per millimeter of rainfall (per drop in this study),

Λ in (m) is the average splash length,

μ is the mass per unit area per millimeter of rainfall (per drop in this study),

r (m) is the radial distance from the point of impact to the center of the ring.

III. Results and Discussion

A. *The Relationship between the Apparent Mass and the Slope Steepness*

The relationship between total soil splash, such as the apparent mass and slope angle, is plotted in Fig. 5.

The same data have been used to calculate the linear regression equation. The general trend for splash loss apparent in Fig. 5 has shown that the total weight splashed downslope increased linearly with slope angle. The statistical analysis of the data has shown that the relationship, between the apparent mass and the slope steepness, is best presented by a linear regression equation with a high coefficient of determination.

Most workers have based their interpretation of splash and slope relationship on the exponent of the power function and some related the variation of this exponent to soil characteristics, among them [8]. The regression equation of this study is:

$$M_{app.} = 0.042\theta + 0.9 \qquad R^2 = 0.94 \tag{3}$$

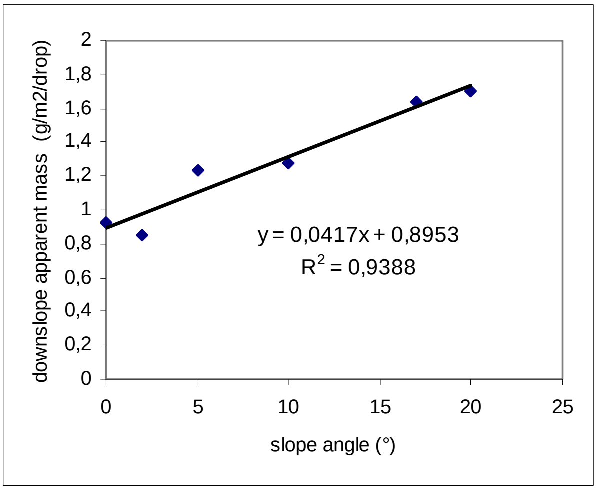

Fig. 5 The relationship between the slope angle and the downslope real and apparent mass under 4mm drop diameter

B. Soil Splash Distribution for Variable Slope Angle

The relationship between the mass received in the compartments, and evaluated by (1), and the distance for different slope angles, between 0° and 20°, is plotted in Fig. 6.

On any slope, raindrop impact projects particles in upslope and downslope directions. In this study, only the particles moved downslope were considered. In the field, particles splashed upslope may be splashed again but in downslope direction, but that input is not selected here. Particles ejected from a point of impact are affected by two kinds of angles; the angle formed between the trajectory and the horizontal plane, and the second angle is the slope angle. This implies that the particles travel further before reaching the surface on a slope and further for steeper slope angle. This interpretation is justified by the results found in this study. From the data, we can remark that, approximately, the same amount of soil splashed in one compartment for one slope angle was found in the next compartment of the next greater slope angle.

Fig. 6 gives more information about the displacement of the particles from the target onto the splash board surface.

On the vertical axis, the mass distribution increased with the slope angle whereas, on the horizontal axis, the mass decreased sharply with the distance in an exponential fashion.

General relationships, between weight of splashed soil downslope and distance from point of impact, have been fitted to the exponential function and presented in Table I. These high coefficients of determination, between mass and distance, show the best fit of the exponential function to the data of this study: mi = a exp(-bl$_i$).

The coefficient ‘a’ ranges between 0.0282 and 0.0064 and the exponent ‘b’ ranges between 6.78 and 7.25 in heterogeneous way. It should be noted that only the constant ‘a’ decreased with the slope angle and the exponent ‘b’ does not explain the effects of the slope angle on the splash distance.

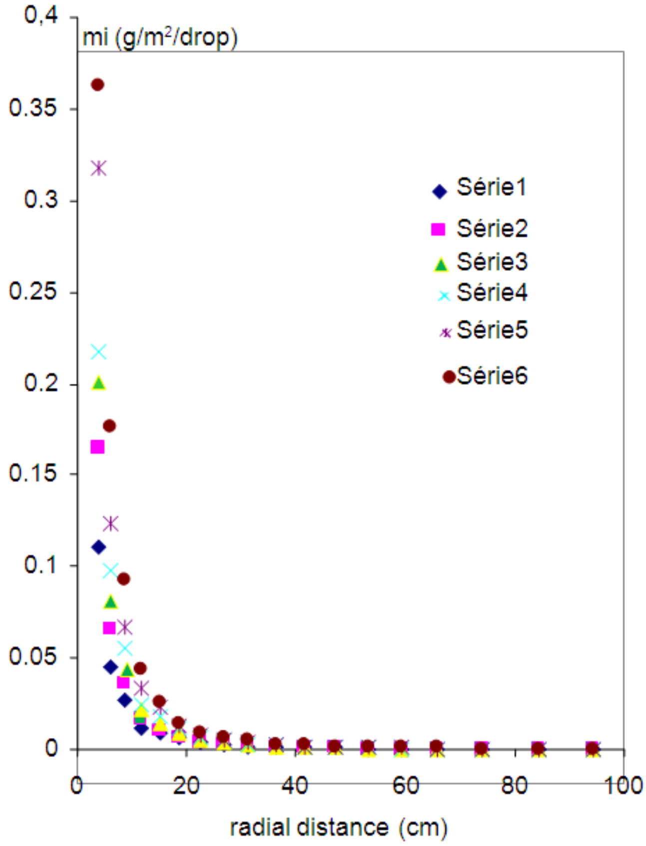

Fig. 6 The relationship between the splashed mass mi (g/m^2/drop) in the compartments and the radial distance for different slope angles. [serie1: 0°, serie2: 2°, serie3: 5°, serie4: 10°, serie5: 17° and serie6: 20°]

As regards the validation of the model of Van Dijk [9], the regression equations for different slope angles have been compared to (3). The measured splash radial distributions, illustrated in Fig. 6, are in accordance with the theory of Van Dijk [9].

This is to say that the spatial distribution of soil particles, for different slope steepness, fits the exponential function and, thus, extends the validity of the FSDF.

TABLE I
THE REGRESSION EQUATIONS AND THE COEFFICIENTS OF DETERMINATION OF THE RELATIONSHIPS BETWEEN THE MASS WEIGHT M$_I$ AND THE RADIAL DISTANCE

Slope angle (°)	Equation	R^2
0	mi = 0.0282e$^{-6.78li}$	0.889
2	mi = 0.0212e$^{-6.56li}$	0.858
5	mi = 0.0178e$^{-6.88li}$	0.893
10	mi = 0.0135e$^{-7.03li}$	0.888
1 7	mi = 0.0101e$^{-7.27li}$	0.888
20	mi = 0.0064e$^{-7.25li}$	0.869

IV. CONCLUSIONS

The effects of slope steepness on total mass detached, such as the apparent mass and on soil splash distribution, could be summarized in these sentences.

The apparent mass detached from the splash cup, under the impact of the rain drops, increased as the slope angle increased. The statistical analysis of the relationship, between the apparent mass and the down slope steepness, has shown that the linear regression equation is the best fit. The coefficient of determination is high and is 0.93.

As regards the spatial distribution of the soil particles for different slope steepness, the mass decreased with radial distance following the exponential function, for every slope angle. The curves illustrated on the figure and the regression equations validate the FSDF and extend the theory of Van Dijk ([9]).

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