International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:7, No:4, 2013

The Effects of Rain and Overland Flow Powers on Agricultural Soil Erodibility

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Abstract**—**The purpose of this investigation is to relate the rain power and the overland flow power to soil erodibility to assess the effects of both parameters on soil erosion using variable rainfall intensity on remoulded agricultural soil. Six rainfall intensities were used to simulate the natural rainfall and are as follows: 12.4mm/h, 20.3mm/h, 28.6mm/h, 52mm/h, 73.5mm/h and 103mm/h. The results have shown that the relationship between overland flow power and rain power is best represented by a linear function (R^2=0.99). As regards the relationships between soil erodibility factor and rain and overland flow powers, the evolution of both parameters with the erodibility factor follow a polynomial function with high coefficient of determination. From their coefficients of determination (R^2=0.95) for rain power and (R^2=0.96) for overland flow power, we can conclude that the flow has more power to detach particles than rain. This could be explained by the fact that the presence of particles, already detached by rain and transported by the flow, give the flow more weight and then contribute to the detachment of particles by collision.

Keywords**—**Laboratory experiments, soil erosion, flow power, erodibility, rainfall intensity.

I. Introduction

IT has been shown that soil erosion by rainfall is the division of work between detachment by raindrops and transport of loose soil particles by overland flow away from the site ([7] supported by [10]). The falling rainfall on rough remoulded agricultural soil complicates the hydraulic parameters such as the velocity, shear stress, shear strength and overland flow power and, consequently, sediment concentration is influenced.

Soil interrill erodibility is the susceptibility of soil to erode within interrill areas [1]. The soil erodibility '*K'* is a dynamic factor which varies between soils (see [5]). Rainsplash energy is an important erosive agent in splash and rainflow erosion which, by modifying soil surface properties and flow hydraulics, can strongly influence interrill and rill erosion [2]. We understand from this that soil erodibility could also be influenced. Soil erodibility could change the flow concentration, which could influence the viscosity and, consequently, the flow regime and overland flow power. The aim of this investigation is to relate the soil erodibility factor to rain power and overland flow power in the purpose to conclude the best predictor of soil detachment.

This investigation follows the previous work of the authors dealing with the influence of rainfall characteristics on runoff and water erosion (see [8]).

II. Basic Equations

A. Rain Power

When rainfall hits the ground, the energy of the drops detaches and disperses the soil particles from the soil matrix. Reference [3] reported that the rain power is the variation of this energy with time and proposed the following expression:

$$P = ½\rho I v^2 \cos\theta \quad (1)$$

where **ρ** is the water density (1000kg/m^3), **I** the rainfall intensity (m/s), **v** the drops velocity (m/s) and **θ** the soil surface angle with the horizontal (°).

B. Overland Flow Power

To represent soil detachment, many authors, among them [9], proposed overland flow power as a best predictor of soil erosion.

$$\Omega = \rho g q_t \sin\theta \quad (2)$$

where $\mathbf{q_t}$ is the total overland flow discharge.

C. Soil Erodibility Factor 'K'

The WEPP (Water Erosion Prediction Project) erosion model expresses interrill erosion [5] as:

$$E = K I^2 S_f \quad (3)$$

K represents the interrill erodibility, **I** the rainfall intensity and $\mathbf{S_f}$ is the slope factor. In WEPP, $\mathbf{S_f}$ was found to be:

$$S_f = 1.05 - 0.85\exp(-4\sin\theta) \quad (4)$$

where **θ** is the soil slope angle in degree.

By definition, sediment concentration of overland flow is expressed by the following equation:

$$C_s = q_t / q_w \quad (5)$$

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where $\mathbf{q_t}$ is sediment discharge (weight of soil/unit of area/unit of time).

$\mathbf{q_w}$ is the water discharge measured at the output of the soil area. The unit flow discharge is given by the continuity equation:

$$q_w = h.U \quad (6)$$

U is the overland flow mean velocity ($U = 2/3U_s$) where $\mathbf{U_s}$ is the free surface velocity and **h** is the mean flow depth. Interrill soil erosion **E** is related to $\mathbf{q_t}$ by the following relationship [5]:

$$E = q_t / L \quad (7)$$

where **L** is the eroding surface length.

The combination of relations (3) and (7) gives this relationship:

$$q_t = K.L.I^2.S_f \quad (8)$$

and the combination of (5)-(8) gives the K factor as follows:

$$K = C_sUh/I^2LS_f \quad (9)$$

III. Equipment and Experimental Procedures

Artificial rainfall is produced using a commercially-available type of nozzle (H1/4VV 8008, H1/4VV 8004, H1/4VV 8002 and TEEJET SS 65 60).

The simulator which is used is an EID 340 ORSTOM type, with a spray nozzle fixed on a gantry at a height of about four meters (Fig. 1 (a), (b)).This simulator, already used by the authors [8], consists of 3 meters steel tube (B), rigidly mounted in a rectangular carriage, which is longer than the flume soil tray (H), in order to cover the total area of the soil.

The carriage that supported the sprinkler (tube with nozzles) was 3 meters above the soil surface and was supported by four bars. Water was centrally supplied by a pump (G) to the sprinkler unit (C), from a tank (E), through a gate valve and pressure gage (F). The sprinkler was calibrated using plastic cups and rainfall intensity was linked to the pressure gage indication.

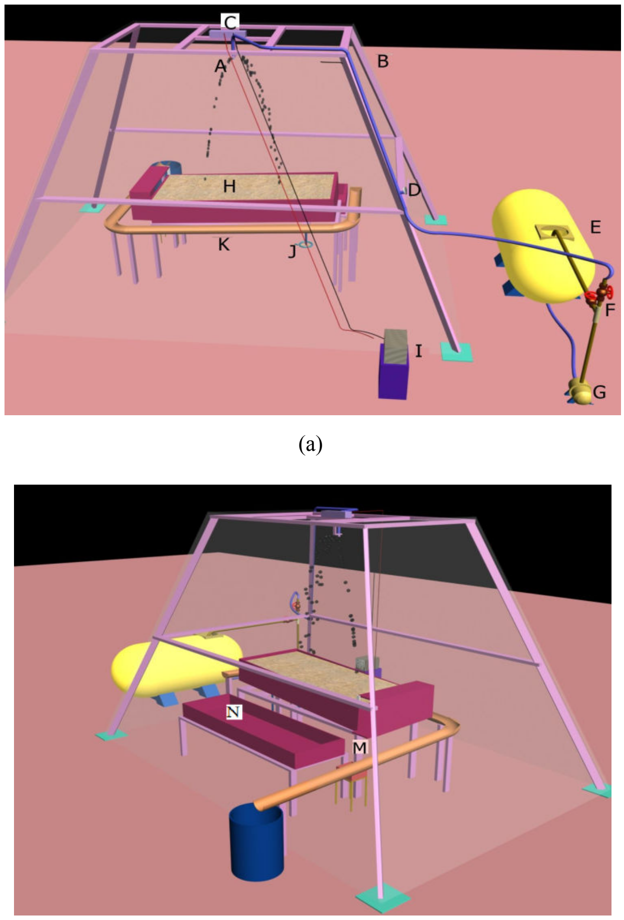
The procedure used to measure the rainfall intensities was the simple volumetric method and are as follows: 12.4mm/h, 20mm/h, 28.5mm/h, 52mm/h, 60.4mm/h, 73.5mm/h and 103mm/h.

The discharge was measured volumetrically. Samples were taken at the output of the tube collector every 3 minutes from the commencement of flow using cylinders of 1000ml and a stop watch of 0.01 second precision to record the time of collection.

The discharge **Q** was determined from the rate of water/sediment mixture volume **W** and time **t** using Q = W/t.

The samples (1000ml), taken for the measurements of discharge, were used to measure the sediment concentration. These samples were stirred vigorously to obtain a homogenous mixture and 200ml of the mixture was taken from each cylinder.

These samples of 200ml were dried in the oven for 24 hours, and the soil residue was used to represent the sediment concentration of the runoff.



(a)

(b)

Fig. 1 (a) Rainfall simulator (back view) (b) Rainfall simulator (front view)

A. Surface Velocity Measurements

The Surface velocity $\mathbf{U_s}$ was measured by tracing the travel of dyes over the distance specified according to the soil tray dimensions. The distance is limited from 0.5m to 2.0m in the purpose to get a uniform flow avoiding the effects of the top edge of the surface flow. To avoid the effects of the rain impact on the dye tracing, a powder of potassium permanganate is used. A small amount is injected in the middle of the surface flow and at 0.5m from the top end of the soil tray. Surface flow velocities were then measured visually by recording the time of the leading edge of the dye cloud travelling between the injection point and 2.0m bottom end of the soil tray. The mean flow velocity **U** is calculated from the surface velocity using the conversion factor of 0.67 (see [4] and [6]).

Mean flow depth **h** was then calculated using h = q/U where **q** is the mixed overland flow discharge and **U** the mean velocity.

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B. Soil Preparation

The soil materiel used to run the experiments was an agricultural soil and was examined for stones and roots which were removed in order to have a homogenous structure. It was consisted of 11.57% silt, 81.22% sand, 7.21% clay and 4.1% organic matter. To run an experiment, a layer of examined soil was deposited and spread gently over the surface tray. To obtain a flat plot, in the purpose to generate a flat sheet of water, a straight piece of hardwood was used to flatten the surface until the top soil is level with the downstream end of the tray. Afterwards, the soil was wetted gently without disturbing the soil structure, with a watering can (fine rain) until saturation, then the rainfall simulator is put on to run the experiment. The slope of the soil tray was fixed on 3% and is appropriate for generating an interrill flow.

IV. Results and Discussion

A. Relationship between the Rain Power and Overland Flow Power

Theoretically, we point out that the powers represented by (1) and (3) are directed by the same parameter *I*. This means that rainfall intensity still the main parameter in determining soil erosion. The difference between these two equations is that (1) is enhanced by the presence of rainfall velocity, which is itself related to rainfall intensity.

The relationship between rain power and overland flow power is best presented by a linear function with a high coefficient of determination $R^2 = 0.99$. From this relationship, when the overland flow is generated by rainfall, the best predictor of soil erosion could be one of these powers. In the becoming sections, both powers are related to soil erodibility factor in the purpose to compare between them.

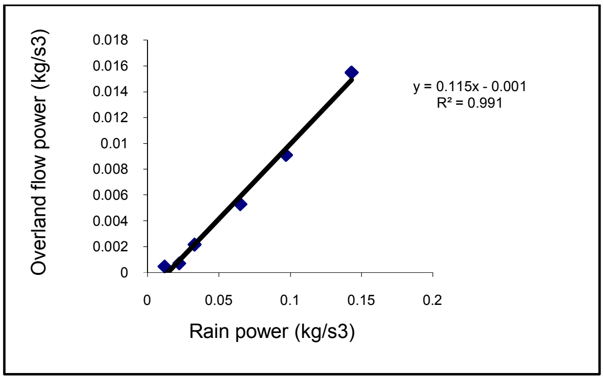

Fig. 2 Relationship between rain power and overland flow power

B. Relationship between Rain Power and Soil Erodibility Factor

When the drop hits the soil, the drop energy is transferred to soil particles.

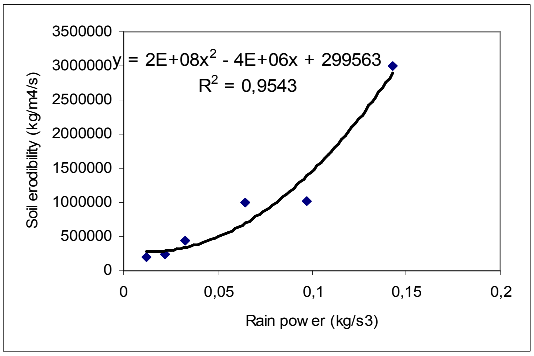

Fig. 3 Relationship between rain power and soil erodibility factor

The reference [3] uses the term "rain power" to describe the rate at which this energy is transferred to the surface. To understand this effect, data representing the soil erodibility and rain power are plotted on Fig. 3. From the shape of the curve and the statistical analyses, we point out that soil erodibility evolves with rain power in a polynomial function with a high coefficient of determination.

C. Relationship between Soil Erodibility Factor and overland Flow Power

The data representing the relationship between the soil erodibility factor and the rain power are plotted on Fig. 3. From the shape of the curve, we point out that the rain power increased with decreasing soil erodibility factor. This phenomenon could be explained experimentally. The soil erodibility is the susceptibility of soil to erosion, which means that the more the flow is powerful the more the sediment concentration is increased and, consequently, the soil erodibility is important.

The statistical analyses have shown that the soil erodibility factor and overland flow power is best described by a polynomial function with a high coefficient of determination of 0.96. The regression equation is presented as follows:

$$K = 9.10^9\Omega^2 + 3.10^7\Omega + 259873 \qquad (R^2 = 0.96) \qquad (10)$$

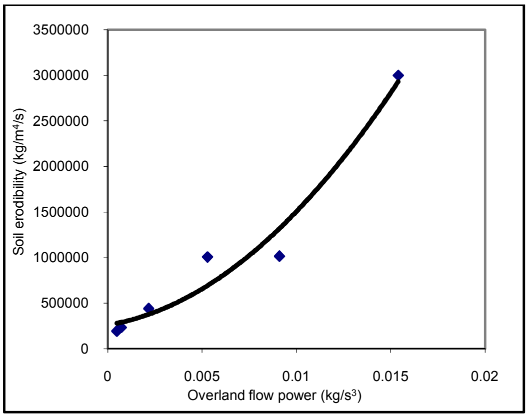

Fig. 4 Relationship between the soil erodibility factor and overland flow power

V. CONCLUSION

The conclusion could be summarized in some points:

- The relationship between rain power and overland flow power is best presented by a linear function, and both parameters could be the best predictor of soil detachment.
- The soil erodibility factor is related to rain power and to overland flow power. Both relationships are a polynomial function with a high coefficient of determination.

ACKNOWLEDGMENT

The authors would like to thank the LEGHYD laboratory (DGRSDT, Algeria) for its financial support.

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