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Laboratory Experiments: Influence of Rainfall Characteristics on Runoff and Water Erosion

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***Abstract*—**The study concerns an experimental investigation in the laboratory of the water erosion using a rainfall simulator. We have focused our attention on the influence of rainfall intensity on some hydraulic characteristics. The results obtained allow us to conclude that there is a significant correlation between rainfall intensity and hydraulic characteristics of runoff (Reynolds number, Froude number) and sediment concentration.

***Keywords*—**Laboratory experiments, rainfall intensity, rainfall simulator, runoff, sediment concentration, soil erosion

I. Introduction

FOR a long time researchers have devoted great efforts to measure runoff and erosion risk on the ground through the plots demarcated by borders and under natural rainfall. These experiences lead to satisfactory results, but they have some disadvantages such as cost, time and the tremendous work that must be provided to perform these experiments

Although rainfall simulators have been used for many subjects, their development is largely from early research on the behavior of soils subjected to rain, particularly in regard to erosion problems. Experiments under natural rainfall had several drawbacks such as variation in intensity and duration of rainfall, initial soil water status, too long observations (several years) if we want to measure exceptional storms. The first attempts to reproduce the rain under controlled conditions, both in field and laboratory, were therefore designed to overcome these disadvantages.

II. Experimental procedure

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. Driven by a pendulum, the nozzle sprays a surface test of $2x1m^2$. The variation of the displacement angle allows the change of the rainfall intensity. The rainfall simulators have to reproduce, on a small area, a rainfall with hydrological parameters close to those observed in the nature: intensity, kinetic energy of raindrops, etc.. The simulator chosen is as used by many authors; only the shape and sizes are modified, as shown schematically in Fig. 1 and Fig. 2. Artificial rainfall is produced using a commercially-available type of nozzle (A: H1/4VV 8008, H1/4VV 8004, H1/4VV 8002 and TEEJET SS 65 60). This simulator 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).

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The sprinkler was calibrated using plastic cups and rainfall intensity was linked to the pressure gage indication.

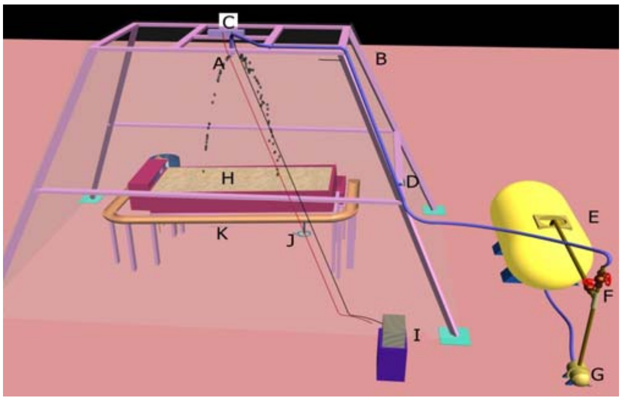

Fig. 1 Rainfall simulator (back view)

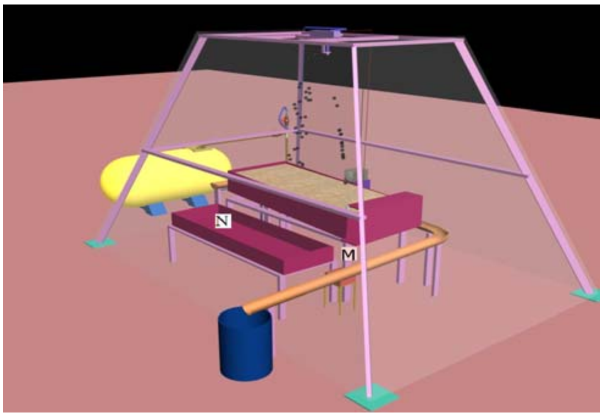

Fig. 2 Rainfall simulator (front view)

To adjust the rainfall intensities, the pressure is varied using the valve and the sprinkler speed by changing the frequency of the battery charger. Many preliminary tests were conducted to obtain rainfall intensities as uniform as possible. Considering the size of the tray, a dense network of raingauges (cups having the same orifice area) was placed on the soil tray. The density used is such that the longitudinal distance between two raingauges is 6.8 cm while the transverse gap is 11.3 cm (see Keller et al. [12]; Montovani et al. [16]; Yacoubi et al. [25]). The duration of the run, to determine the rainfall intensity, was 10 minutes and 30 minutes. The volume of water collected in each gauge is measured in a graduated cylinder, and this volume divided by the fixed duration and the orifice area of the gauge which determined the rainfall intensity. The mean value of the experiment is the mean of five runs. The variation of the rainfall intensity was controlled by the valve situated between the output of the pump and the pressure gauge. The rainfall intensities, used in these experiments, are as follows: 103 mm/h, 73 mm/h, 60 mm/h, 28 mm/h, 20 mm/h and 12 mm/h.

Concerning the uniform distribution of raindrops on the soil surface, the Christiansen coefficient Cu, which must be greater than 80%, is estimated.

TABLE I
RAINFALL INTENSITIES AND UNIFORMITY COEFFICIENT

Nozzle type	t (mn)	I (mm/h)	Cu (%)
	10	103	82
	10	74	92
TEEJET SS 65 60	10	60	82
	10	52	93
H1/4VV 8008	10	29	90
	20	20	92
H1/4VV 8002	30	12	87

III. Results

A. Raindrop characteristics

The evolution of the median raindrop diameter D_{50} with the rainfall intensity is shown in the Fig. 3.

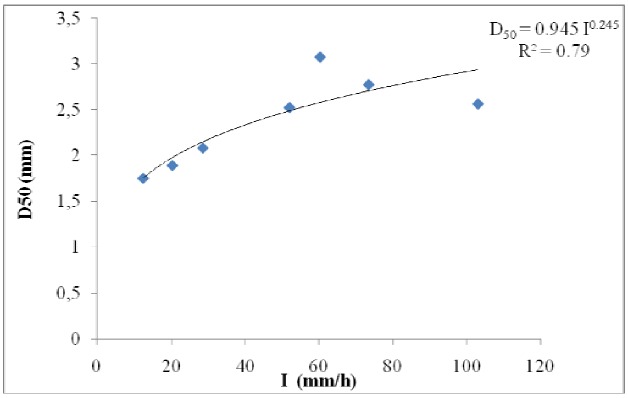

Fig. 3 Median raindrop diameter versus rainfall intensity

The obtained results show that the correlation between the median diameter and the rainfall intensity are much closer to those obtained by Atlas [2] and Willis [23], than those of Laws et al. [14] and Brandt [3]. The power relationship has been established by several researchers (Laws et al. [14]; Hudson [10]; Uijlenhoet et al. [20]; Van Dijk et al. [21]; Carter et al., [4]) where the median raindrop diameter increases with the rainfall intensity. Nevertheless, we note that the D_{50} diameter does not increase indefinitely with the rainfall intensity **I** because, beyond a certain limit, the drops become unstable and break up into smaller drops (Hudson [11]). In addition, the drop diameter sometimes increases and sometimes decreases with the rainfall intensity (Laws et al. [14]).

B. Rainfall intensity and runoff characteristics

The Reynolds number values vary between 23 and 192 for rainfall intensities ranging from 12 mm/h to 103 mm/h. The evolution of the Reynolds number follows the power law with a highly significant correlation coefficient.

These values are slightly different from those reported by Guy et al. [9] with values ranging from 36 to 160 for rainfall intensities ranging from 45 mm/h to 180 mm/h. However, the Reynolds numbers of this study are lower than those reported by Gilley et al. [7]. Indeed, they found Reynolds numbers ranging from 126 to 900 for intensities ranging from 13 mm/h to 144 mm/h and a slope angle varying from 0.5 to 1%.

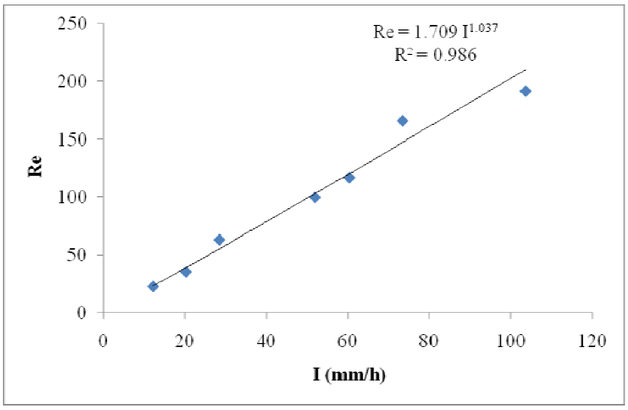

Fig. 4 Reynolds number versus and rainfall intensity

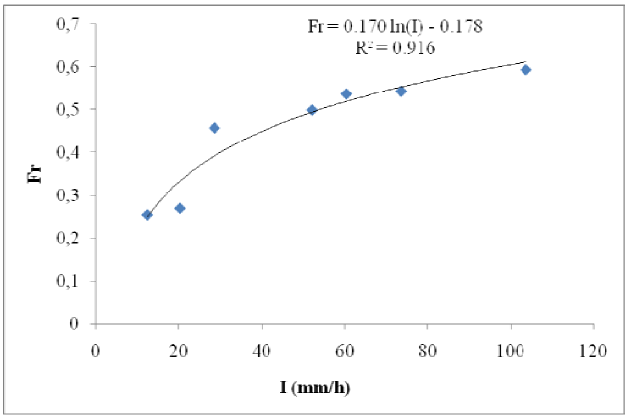

Fig. 5 Froude number versus rainfall intensity

For the full range of rainfall intensities, the Froude number obtained is less than 1.Those results are consistent with those of Mouzai [17], which means that the regime is subcritical. The results show that the Froude number increases with increasing intensity and, as shown in Figure 5, it follows well a quite logarithmic function form. It should be noted that Walker et al. [22] also showed that, for a rainfall intensity of 45 mm/h, with a slope angle of 2.86 °, the runoff flow is subcritical.

The power flow Ω increases with the increase of the rainfall intensity with values from 0.002 kg/s^3 to 0.015 kg/s^3 for rainfall intensities ranging from 12.39 mm/h to 103.01 mm/h. The relationship between power flow and intensity of rain is shown in Figure 6. The graph follows a power function with a correlation coefficient enough large.

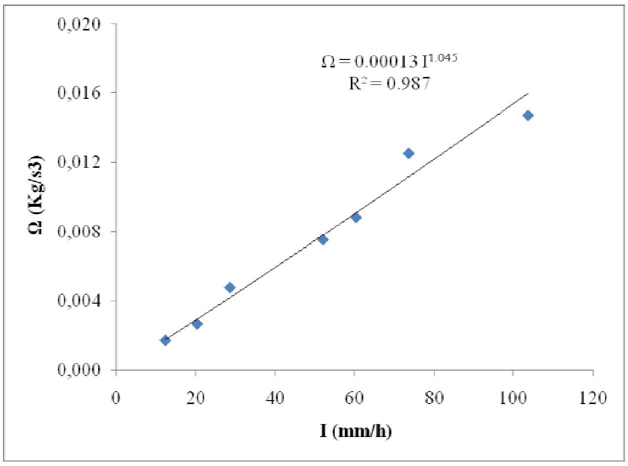

Fig. 6 Power flow versus rainfall intensity

C. Rainfall characteristics and sediment concentration

From the obtained results, we note that the increasing of the sediments concentration Cs follows that of the rainfall intensity. Wischmeier and Smith [24] found that high currents cause significant soil losses. The increase in flow velocity, which was induced by the rainfall intensity, favors uplift of soil particles, which justifies the change in concentration with the rainfall intensity.

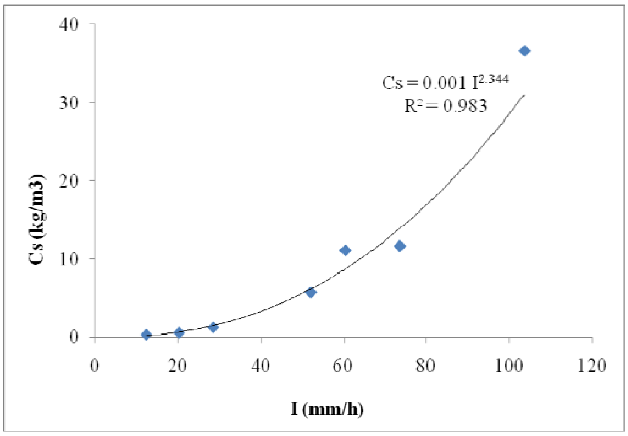

Fig. 7 Sediment concentration versus rainfall intensity

Mouzai [17] showed that the sediment concentration decreases with increasing rainfall using high intensities. Kilinc et al. [13], when studying the mechanics of soil erosion, used four rainfall intensities on sandy soil and six slope angles (5.7%, 10%, 15%, 20%, 30% and 40%). They found that the sediment concentration increases with increasing rainfall intensity for each slope angle, although they did not give, for each intensity, the values of the raindrop diameter. Figure 7 shows the correlation between sediment concentration and rainfall intensity. The power law gives a highly significant correlation coefficient.

IV. Conclusion

This experimental work has allowed us to understand the effects of rainfall characteristics on runoff and mechanical sediment concentration.

Our objective was to study the relationships between rainfall characteristics and more specifically the rainfall intensity, the kinetic energy and erosive power, with the Reynolds number, the Froude number, the power of the flow and the concentration of sediment.

The results we obtained seem satisfactory. To quantify the rainfall kinetic energy, we used the simple absorbent paper method, although it requires a long counting.

The relationship between the raindrops kinetic energy and the rainfall intensity is not significantly different from those of Willis [23], Atlas [2], Laws et al. [14].

According to the results, it was found that when increasing the rainfall intensity, all the characteristics increase. The relationship that determines this dependence was given with a significant correlation coefficient. For rainfall intensity from 23 mm/h to 103 mm/h, the Reynolds number ranges from 23 to 187.

These results are validated by those of Guy et al. [9] and the flow regime remains laminar (Re<500). For these intensities, the Froude number remains less than 1; the flow regime is subcritical. The evolution of the rainfall intensity induced increase in the flow velocity. Therefore, the tearing of the particles increases, which justifies the increase in sediment concentration.

The evolution of the kinetic energy of raindrops induced the increase of Reynolds number and Froude number. The relationship follows the well-polynomial function. The kinetic energy of raindrops has a significant effect on sediment concentration; the correlation is represented by a power law.

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