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S.T.O.R.M.-1 : A DEVICE FOR THE SIMULATION OF OBLIQUE RAIN. FIRST APPLICATIONS ON TROPICAL SOILS AND OTHERS

S.T.O.R.M.-1 : un appareil de simulation des pluies obliques. Premières applications à différents types de sol tropicaux et autres

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RESUME

Les dernières années, les méthodes de simulation de pluie ont connu un développement considérable. A l'heure actuelle, il existe des simulateurs, capables de produire des pluies artificielles, conformes aux pluies naturelles du point de vue du diamètre moyen des gouttes et de l'énergie cinétique produite. Néanmoins, un des caractères les plus importants, l'obliquité d'une pluie naturelle, n'a jamais pu être simulé de manière satisfaisante.

A l'occasion d'une recherche géomorphologique au Rwanda, on a éprouvé le besoin de construire un nouveau type de simulateur qui comble cette lacune. Sur base d'une nouvelle technologie, l'appareil, surnommé S.T.O.R.M.-1, produit une pluie artificielle dont la trajectoire des gouttes croise la verticale avec un angle qui peut varier entre 5° et 35°. En même temps, le diamètre moyen des gouttes, ainsi que leur vitesse terminale, peuvent être modifiés.

Trois expériences sont décrites. Elles montrent l'influence de l'obliquité de la pluie sur la direction du splash pour un sol sablonneux et sur la capacité d'infiltration d'un sol sablo-argileux.

ABSTRACT

Lately, there has been a considerable improvement of rain simulation methods. Today, many simulation devices duplicate natural rainfall conditions in respect to mean drop diameter and cinetic energy. Nevertheless, the rainfall obliquity, one of the most important characteristics of natural rains, has not yet been simulated in a satisfactory way.

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On the occasion of geomorphological work in Rwanda, it was felt necessary to develop a new type of rain simulation device, in order to meet this need. Based on a different technological principle, the apparatus, called S.T.O.R.M.-1, produces a spray of drops, the size and terminal velocity of which can be adapted. The drop trajectory crosses the vertical with an angle varying between 5° and 35°.

Three experiments are described. They show the splash transport direction on a sandy soil and infiltration capacity of a clayey-sandy soil to be related with the rainfall obliquity.

INTRODUCTION

Rain simulation in laboratory and field conditions plays an increasing role in the study of erosion mechanics and soil behaviour related to ecological, agronomical, engineering and geomorphological research throughout the world and especially in tropical regions. This trend led to the development of different types of rain simulators during the last decades (BUBENZER, 1979; ZANCHI, 1979). It is, however, surprising that no appreciable effort has been made to build rain simulation devices producing oblique artifical rain. With actual rain simulation technology, "raindrop impacts that are nearly vertical, are the only type that can be reasonably simulated in a controlled manner that is uniform over the entire area" (MEYER, 1979). Hence, natural rain often falls with a horizontal velocity component due to wind. Moreover, as air pressure systems in many parts of the world are permanent or semi-permanent in character, it can be supposed that rain obliquity very often has a strong unidirectional component throughout the year. This is the case in eastern equatorial Africa, where personal observations in Rwanda since 1975 have shown that at least nine out of ten rain storms are carried by easterly winds and show a clear east-west component in their obliquity. Even in western Europe, where meteorological conditions are highly variable, a high proportion of the precipitation falls in a direction with a strong west-east component. In both cases, the question arises to the effect of oriented rain obliquity in long and short terms.

In 1977, a geomorphological research program started in Rwanda (MOEYERSONS, 1978). This research is subsidized by funds provided for in The Belgian-Rwandian Convention relating to the *Institut National de Recherche Scientifique* of Rwanda. On this occasion, it was decided to start laboratory investigations concerning the influence of the horizontal velocity component of wind driven rain on various aspects of rain erosion. For this purpose, a rain simulation device has been developed at the *Koninklijk Museum voor Midden-Afrika*, Tervuren - Belgium. It is a laboratory apparatus producing oblique artificial rain and is called "Special Tervuren Oblique Rain Modulator 1". This article gives a short description of the apparatus S.T.O.R.M.-1 and of the characteristics of the artificial rain produced. It also mentions the preliminary results of three experiments, concerning splash transport intensity, runoff coefficients and runoff generation in conditions of simulated oblique rain.

SHORT DESCRIPTION OF S.T.O.R.M.-1 AND THE CHARACTERISTICS OF THE RAIN PRODUCED

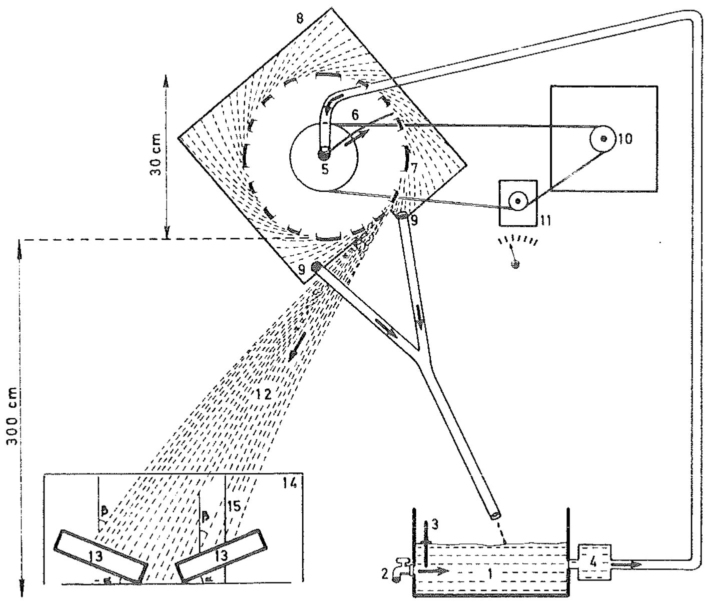

Fig. 1 : Construction scheme of S.T.O.R.M.-1. 1 : réservoir; 2 : electrical faucet; 3 : floater; 4 : pump; 5 : hollow shaft; 6 : water jets; 7 : cylindrical drum with perforated mantle; 8 : recuperation box; 9 : outlets; 10 : electrically driven motor with variable rotation velocity; 11 : revolution-counter; 12 : rain spray; 13 : recipients with soil material : - α for slope inward rain; α for slope outward rain; 14 : screen to measure or estimate β; 15 : vertical plane in which the lateral inclination μ is measured.

A construction sheme of S.T.O.R.M.-1 is given in figure 1. The vital part of the apparatus consists of an aluminium cylindrical drum with a perforated mantle (7). This drum is suspended at a height of 3 metres.

Water is supplied in the inner side of the mantle surface by means of small water jets (6), coming out of 4 perforations, with a diameter of 5 millimeters, made in the hollow shaft (5), around which the drum rotates in the direction as indicated in the figure. As a result of centrifugal forces, this water is drained to 5 cm diameter perforations in the mantle. The water drops, released from these apertures start a trajectory, tangent to the drum mantle, at the same speed as the rotation velocity of the cylinder. Most of the drops are intercepted by the box (8), from where the water flows through outlets (9) to the reservoir (1). A small part of the drops escape through a 10 cm wide window in the box (8) and constitute a diverging oblique spray of artificial rain. The water level in the reservoir (1) is maintained constant within narrow limits, water being automatically added from a public waterworks network terminal. This was necessary in order to keep a constant water supply from the electrical pump (4) to the shaft (5). The water discharge from the pump (4), determining the rainfall intensity, can be controlled by a faucet between the pump (4) and the shaft (5). The direction of the artificial rain spray and, hence, the mean angle of drop indidence is controlled by the position of the box (8), which can be turned around an axis lying in direct line with the shaft (5). It was pointed out that the mean diameter of the drops is influenced by the distance, measured along the cylinder mantle, between the point of impact of the water jets (6) on the inner side of the mantle, and the window in the box (8). The frame has, therefore, been made as such that the shaft (5) can be turned around independently in order to maintain the relative position of the water jets (6) and the box (8). In this way, the mean drop diameter can be held constant, no matter the position of the box (8). The characteristics of the artificial rain produced by S.T.O.R.M.-1 further depends of the combination of discharge of the pump (4), the rotation time of the drum, and the number of the 5 cm wide perforations, left open in the mantle surface of the drum. During the calibration period, it has been stated that, with the given perforation diameter of 5 cm and a given position of the box (8) and the shaft (5), the mean drop diameter in the artificial rain spray increases :

- with an increasing discharge from pump (4)
- with an increasing rotation time of the drum
- with a decreasing number of 5 cm diameter perforations, left open as shown in figure 1. The mantle surface is provided with 64 perforations, i.e. 16 lines of 4 perforations each. When artificial rain is desired

with arbitrary characteristics of obliquity, intensity and mean drop velocity and diameter, the box (8) is first put in an adequate position, and the desired rotation velocity is given to the drum. Then rainfall intensity is measured and the pump (4) discharge is consequently adapted. Finally, a number of perforations in the drum mantle is closed until the spectrum of drop diameters falls within the desired range. The two last operations should be repeated.

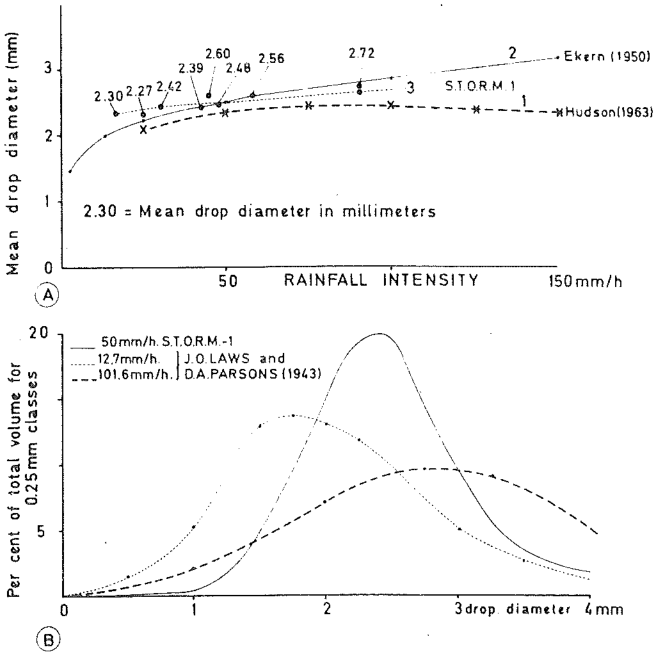

Fig. 2 : A : mean drop diameter below S.T.O.R.M.-1 compared with mean drop diameters for natural rain. The measurements were done with the blotting-paper method during the determination of the infiltration envelopes (see third experiment) for β = 20° and α = 19.88°; B : comparison of S.T.O.R.M.-1 raindrop population with natural rain-drop population for β = 20°.

The two years of experience with S.T.O.R.M.-1 have shown that no calibration is needed for different rainfall intensities, once the apparatus is adapted to a well defined intensity. Indeed, S.T.O.R.M.-1 produces rain with mean drop diameter which increases automatically with increasing rainfall intensity. The mean drop diameter is not so far from the one for natural rain measured by EKERN (1950) and HUDSON (1963). This is illustred in figure 2 A and can be explained as following. When the intensity of simulated rainfall must be increased, the rotation velocity must be increased as well, according to the larger size of drops which are intended to be produced. A simple increase of rotation velocity causes a fall in mean drop size, but this effect is slightly overcompensated as a result of higher discharge.

While the mean drop size is one criterion to characterize a precipitation, the *calibration* or the range of drop diameters in a raindrop population is also important. Some authors, such as LAWS (1941), LAWS and PARSONS (1943), and HUDSON (1961) published graphs indicating the percentage of total volume contributed by drops of various sizes. Comparision of the rain produced by S.T.O.R.M.-1 and the data mentioned above shows that in general the bell-shape of the S.T.O.R.M.-1 rain population is narrower than those obtained for natural rains (Fig. 2 B).

S.T.O.R.M.-1 produces a rain spray, which has well known characteristics concerning drop velocity, mean drop diameter, orientation and discharge at the window in the box (8). These characteristics are different at the surface of an experimental box which stands about 2.5 m below the drum. A water drop released from the drum follows a trajectory, which, in the beginning, describes a straight line tangent ot the mantle surface of the drum. From the moment of release onwards, however, its horizontal velocity component diminishes as a result of air resistance. Its vertical velocity component will eventually tend to reach the terminal fall velocity which corresponds to the diameter of the drop. In this way, the free fall below the apparatus allows a certain adaptation of the vertical velocity component of every single drop, according to its size. Therefore, if all drops are released from the cylinder mantle with a vertical velocity component adapted to the mean diameter drops, not only the modal size drops, but also the smaller and larger ones, reach a vertical velocity component equal to their typical terminal vertical fall velocity when they hit the ground surface. From this point of view, to somewhat too narrow range of raindrop diameters in S.T.O.R.M.-1 rains is an advantage when final drop velocities are concerned. Not only mean diameter drops, but nearly all the smaller ones from the spectrum as well as the major part of the larger drops reach a 100 % cinetic energy. This is only a theoritical statement of course, which is based on the hypothesis that natural raindrops, falling obliquely, have a vertical velocity component equal to the vertical terminal fall velocity (HUDSON, 1961). In fact, the literature does not provide data of the fall velocity of water drops driven by side-winds. Besides these advantage concerning cinetic energy, S.T.O.R.M.-1 has some restrictions, the most important being the fact that only a reduced part of the total impluvium can be used. Indeed, within the impluvium the horizontal velocity component of the rain differs from the near end to the far end of the impluvium. This is due to the fact that the artificial rain forms a divergent spray. In the worst conditions when very high obliquity is required, the angle of incidence may increase up to 1° measured on the floor every 10 cm from the near to the far end of the impluvium. It has also been stated that drop diameters are somewhat higher and rainfall intensity somewhat lower in the direction away from the rain simulation device. However, the experience with S.T.O.R.M.-1 has shown that in the not too extreme conditions (rainfall intensity between 30 mm/h and 130 mm/h, and an angle of incidence on a horizontal surface above 70°), test surfaces of 40 cm long and 25 cm wide can be used in the centre of the impluvium. Within such close limits, the produced rain can be considered as homogeneous.

A last point should be emphasised. The S.T.O.R.M.-1 rainfall characteristics, as they are given here are not absolute. They are only examples of the possibilities of the apparatus. Indeed, every change in horizontal velocity component of the artificial rain needs a new calibration. Hence, the results shown in figure 2 are only valid in this particular case.

METHODS TO MEASURE RAIN CHARACTERISTICS AND SYMBOLS TO DESCRIBE EXPERIMENTAL SET UP

It is obvious that the S.T.O.R.M.-1 rain characteristics should be measured as close as possible to the object which has to be subjected to rain. Rain intensities are measured with a funnel, collecting the quantity of water, fallen during a certain time upon its horizontal open surface of known dimensions. In order to obtain reliable data, the measurement should take at least one minute.

To define the rainfall obliquity, a screen is put in vertical position close to the experimental box and oriented in the direction of the rain spray as shown in figure 1. After a few seconds, wet lines appear when falling drops lightly touch the wooden screen. The inclination of these lines can accurately be measured. A variant of this methods consists in using a screen on which lines of different inclinations are traced and in estimating the rain obliquity in counter-light in comparaison with the lines on the screen.

Drop diameters are a very important rain characteristic. At first, they were measured by the flour-method, as LAWS and PARSONS (1943) did before. It could, however, be observed that the dough-pellets, produced by the drops schrunck considerably when they dried out. So, to classify the pellets into groups to different sizes, sieving tests had no sense for the types of flour used. It was, therefore, decided to measure the diameter of the crater impacts in the flour. This was done with a vernier callipers accurate to 1 : 10 mm. Drop size distribution curves were drawn on the base of 200 measurements (Fig. 2 B).

Only recently, a simple test has been applied which, within a few minutes, give the mean drop diameter and even a good idea of the rainfall intensity. The method consists in exposing a piece of blotting paper of known weight and known surface in a horizontal position to the artificial rain during an accurately measured short time of a few seconds. Counting the number of impacts and reweighing the paper immediately after exposure makes the necessary calculations possible. The use of blotting-papers of 5 cm x 5 cm allows to check the entire impluvium of S.T.O.R.M.-1 within about 10 minutes.

As S.T.O.R.M.-1 allows many combinations of different degrees of rainfall obliquity with different slope inclinations of the soil containing recipient, it seemed necessary to develop a technical language and to use symbols, in order to define correctly every possible combination. The first symbol, β, indicates the obliquity of the rainfall. It stands for the angle between a vertical line and the raindrop trajectory. So a vertical rain is indicated as $\beta = 0$. A β value of 90° indicates a horizontal rain, but cannot be simulated by S.T.O.R.M.-1. The slope of the experimental box is given by the inclination of two axes. The first axis lies in a plane perpendicular to the centre of the shaft (5) of S.T.O.R.M.-1. The inclination of the axis is given by symbol α. The slope inclination is considered as negative when the slope is exposed to the rain. This type of rain is called a slope inward rain. A slope outward rain is indicated by a positive value of α. Figure 1 illustrates these combinations. From the use of the symbols α and β, it follows that the angle of drop incidence equals 90° for $\beta = - \alpha$. The second axis which co-defines the slope of the experimental box, lies in a vertical plane, passing through the centre of the box and parallel to the shaft (5). The symbol μ is used to express the inclination of the axis. Negative μ values are not considered because an inclination to one or another side creates needless situations in reverse. When $\alpha = 0$, and $\mu = 0$, then is the horizontal velocity component of the simulated rain parallel to the slope contours; such type of rain is called here a transverse rain.

THREE EXPERIMENTS WITH OBLIQUE RAIN SIMULATION

Splash experiment with $\beta = 7.5°$ and $15°$, α varying from $- 30°$ to $+ 30°$, $\mu = 0$.

This experiment was considered as a simple reconnaissance tour within the large unexplored field of the phenomenon of splash under oblique rain. A simple set up was used in a first attempt to answer the fundamental question whether the net splash transport orientation is only a function of slope direction or not. The experiment was carried out with sands, taken at the fossil dune of Meer in Northern Belgium (VAN NOTEN *et al.*, 1978). These sands are medium-sized. The granulometric modal value of the sample used varies between 156 and 166 micron. The sample contains coarse silt (63 - 32 micron) for 10 % of its weight. This sand was laid down in an iron recipient 4 cm high, 20 cm wide and 40 cm long. The bottom of the box showed 85 perforations of 8 mm diameter, which were covered with a piece of textile. In this way, a satisfying drainage of the permeable sands was obtained. The dry bulk density amounted to 1.3 gr/cm^3. The procedure consisted in subjecting the filled recipient to a 30' rain shower with an intensity of about 50 mm/h, the recipient being inclined along its long axis. This was done for a wide range of α-values and for every α-value it was at least once repeated. A wooden 70 cm x 50 cm tray, put in a horizontal position at the upper and lower edge of the box was used to collect the material splashed in upslope and downslope direction as illustrated in figure 3. After every shower, the collected material was weighted. The dimensions of the trays were apparently sufficient to intercept at least 90 % of the material, splashed in upslope or downslope direction behing the edges of the recipient and their lateral extension.

The recipient filled with sand is considered to represent a vegetation less section from the inter-rill area of a natural slope. The material, collected in every tray can be considered as the contribution of a 40 cm x 20 cm natural slope section to the total upslope and downslope splash transport. It is obvious that this simple measurement does not take the mean saltation distance into account nor other factors needed to calculate accurately the net resultant of splash transport. Therefore the results shown in figure 3 are only considered as preliminary until a

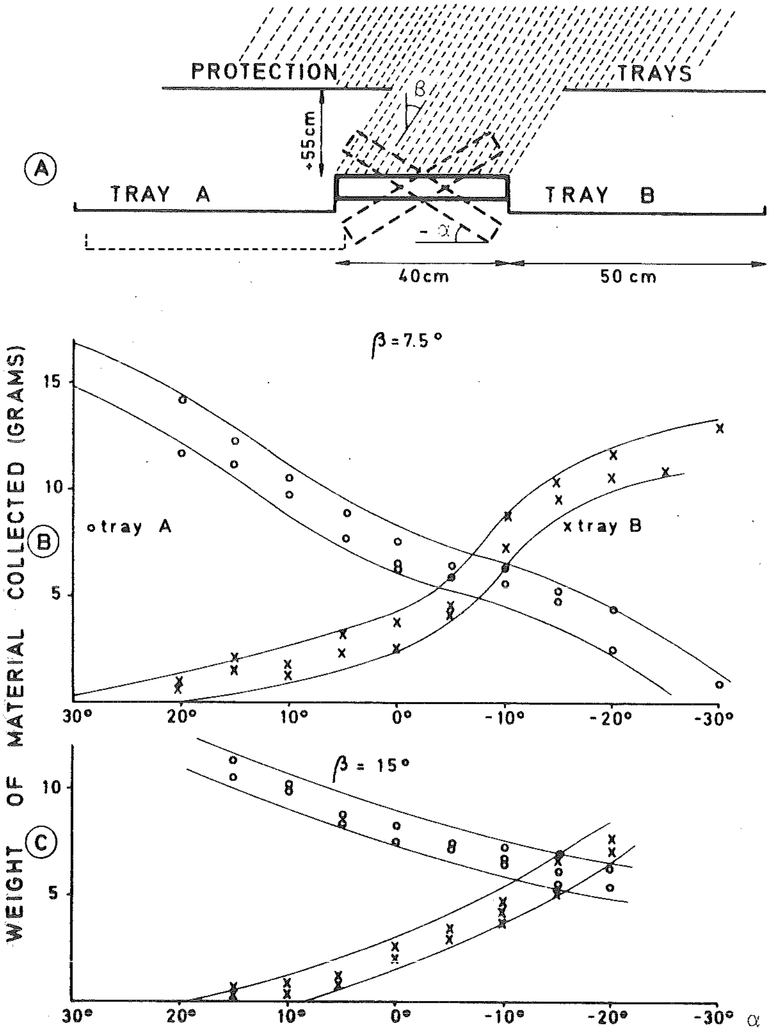

Fig. 3 : The splash experiment. A : experiment set up; B : material collected for β = 7.5°; C : material collected for β = 15°.

more complete investigation will be carried out. Nevertheless, they strongly suggest some interesting points. First of all, the loss of material from the recipient is about the same in upslope and downslope direction for a position where $\beta = -\alpha$. Taken into account the visual observation that the patches of sediment in both trays had about the same extension, it can be assumed that in this position the mean upslope and downslope saltation distances are not very different. Secondly, for $\beta = 7.5°$ as well for $\beta = 15°$, there is no doubt that the net splash transport for $\alpha = 0°$ goes in the same direction as the horizontal velocity component of the rainfall. Indeed, there was not only more material collected in tray A, but the main saltation distances were also substantially greater in the same direction as could be decided from the extension of the patches of the collected sediments.

Hence, the experiment indicates that the orientation of the net splash transport is highly influenced by the orientation of rain. This preliminary conclusion seems even more certain for natural conditions as the contribution of wind to the saltation distances is completely neglected in the experiment. It is believed that these results, although preliminary and incomplete, give an orientation to further research in this field. They indicate that unidirectional splash saltation of sands occurs in flat areas during rainstorms with wind velocities below the wind saltation threshold.

It seems that long distance splash saltation transport is perfectly possible. This might lead to the re-evaluation of splash as a geomorphological factor, even on a regional scale.

Runoff coefficients on the weathering product of schist from Rwaza-hill, Rwanda

Field observations in Rwanda have shown that erosion by diffuse overland flow is very important. The two experiments described here below were an attempt to find out whether variations in the angle of drop incidence are reflected in the soil infiltration capacity. Both experiments were done with material, coming from the 50 cm thick humic A-horizon on Rwaza hill in Southern Rwanda. It is a dark-brown earth, containing about 4 % humic material. Granulometric analyses have shown that the material is badly sorted; it contains about 20 % of clay (less than 2 micron and colloids), about 40 % of silt (63-2 micron) and 30 % of sand (2000-63 micron). The soil also contains a not unimportant amount of gravel sized quartzites and iron nodules. The first experiment intended to measure the infiltration rate of the soil in wet conditions with low soil tension as towards the end of the rainy season, during a rain shower provoking diffuse overland flow on an interrill area. In this experiment a box as illustrated in figure 4 was used. Twenty five perforation with a diameter of 10 mm were made in the bottom. The soil material was laid in this box upon a 2 cm thick layer of artificial gravel, in order to obtain a satisfactory drainage. The box was filled up to 1 or 2 mm below the rim

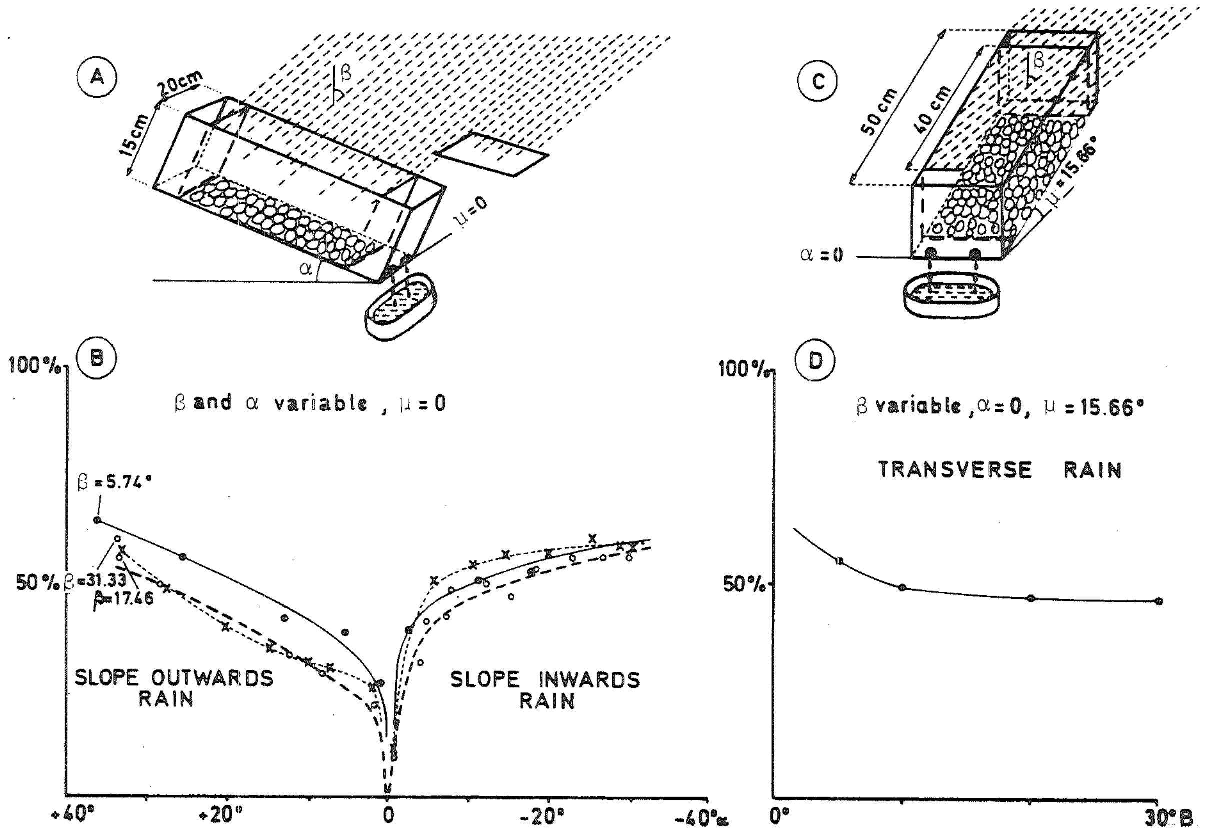

Fig. 4 : Determination of runoff coefficients. A : set up for slope inward and slope outward rains; B : results for A : for β = 5.74°, I_s = 59 mm/h; for β = 17.46°, I_s = 68 mm/h; for β = 31.33°, I_s = 51 mm/h; C : set up for transverse rain : I_s = 59 mm/h; D : results for C.

and the earth was compacted by using artificial rain in long and short showers of different intensity, dispersed over a period of one week. A dry bulk density of 1.35 gr/cm^3 was obtained. This value lies in the range of dry bulk densities as measured on Rwaza hill. The procedure of the experiment consisted in measuring the quantity of runoff during artificial rain at a steady state condition of percolation through the artificial soil column. The runoff coefficient equals the percentage of water falling on the recipient. The box was always inclined along its long axis and situations of slope inward, slope outward, and transverse rains were simulated. Every measurement was done after the installation of the equilibriun between percolation and runoff and it took one minute. Every measurement was repeated 3 times or more. A sequence of situations going from slope inward to slope outward rains was simulated for $\beta = 5.74°$, $\beta = 17.46°$ and $\beta = 31.33°$ with a variable α-value and $\mu = 0$. Transverse rains were simulated for $\alpha = 0$, $\mu = 15.66°$ and β varying from 30° to 5°. The results are graphically represented in figure 4. It has to be mentioned that the loss of water by splash could not be taken into account. This may influence the results, but it is believed that they cannot be responsible for the dissymmetrical character of the graphs, as the loss of water by splash is more important for slope inward than for slope outwards rains.

Graphs 4 B show that runoff coefficients are higher for slope inward rains, especially for α-values between 0° and - 30°. This trend is more pronounced for higher values of β.

Graph 4 D gives the results for transverse rains with different β-values. Here the runoff coefficient increases with decreasing β. We feel unable to explain all the graphs in detail as the runoff coefficient probably results from the combined situation of slope, exposure and rain obliquity. It is clear, however, that the direction of the horizontal velocity component shows a relation with the configuration of the graphs. The experiment with transverse rain indicates that the angle at which drops strike the inclined surface at least co-defines the runoff coefficient. While these results are interesting from the theorical point of view as an attempt to understand the physics of runoff generation and maintenance, the question arises what they teach us concerning field situations. In how far represents the simulation a realistic natural situation ? On the base of our observations in Rwanda, it is believed that the vegetationless, not too compacted sediment in the recipient is a reproduction of a small section of a fallow field. The results suggest that fallow fields exposed towards the rain produce more runoff than other fallows, not only because they receive a higher amount of rain but also because they have a higher runoff coefficient. Hence, it is believed that, in proportion, fallows receiving slope inward rains undergo more erosion.

Determination of mass infiltration for slope inward and slope outward rain

Mass infiltration is the total amount of rainfall which infiltrates into a soil surface before runoff starts. Repeatedly measured on the same soil section with the same initial moisture content, it is merely function of the rainfall intensity (EMBLETON and THORNES, 1979). In a time to ponding-rainfall intensity diagram, the infiltration envelope (SMITH, 1972) gives all possible mass infiltration values for a well defined soil surface at a constant initial moisture content. Infiltration envelopes from different soils allow to compare soil behaviour concerning runoff generation.

In the experiment described here below, infiltration envelopes were defined on the same artificial soil column for different situations of slope inward and slope outward rains. As the analysis of the infiltration envelopes is still in progress, we now report the mass infiltration values as calculated for rainfall intensity of 50 mm/h.

The experiment was carried out with the same sediment and the same recipient as used for the determination of the runoff coefficients. The recipient was always inclined along its long axis, only α-inclinations and no μ-inclinations being used. For every measurement, the sediment was at an initial water content of 33 %. Which means a saturation degree of 95 % as it occurs in the top layer in the field towards the end of the rainy season during a rain shower. This still allowed to perform the measurements without occurrence of percolation through the artificial soil column. Soil tension within the sample could therefore be taken for realistic. The extreme 2 cm of the surface of the sediment were fixed and made waterproof by application of a sealing wax called *Archeoderm* (Fig. 5). A board at each side of the box did not only prevent rain from falling upon the sealed surfaces but also impeded the splash from the intercepted rain to reach the recipient. The time to ponding was arbitrary taken as the time in seconds between the start of the artificial rain and the moment at which the first water arrived over the

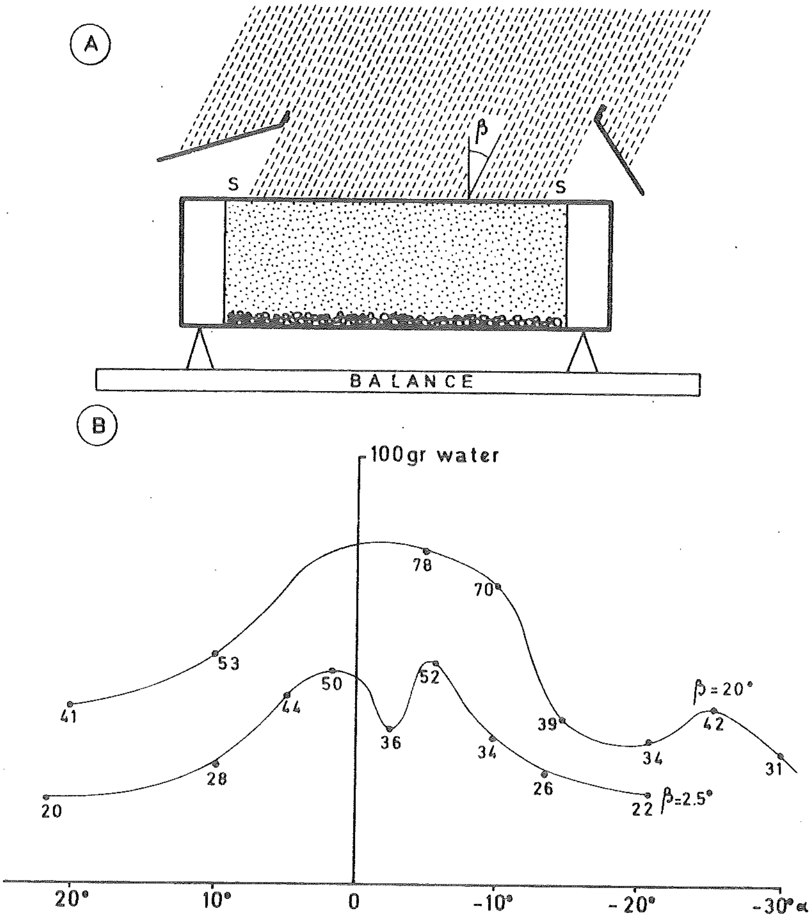

Fig. 5 : Determination of mass infiltration. A : set up : S = sealed surface; B : mass infiltration (grams water) to slope inclination for β = 20° and β = 2.5°.

sealed soil surface at the edge of the box. The box itself was placed on a balance. The applied rainfall intensity could be calculated by means of the time to ponding and the difference in weight of the box between the first moment of the rain and the ponding moment, given the area exposed to rain. The intensity was recalculated for a horizontal surface and was in fact the difference between the gross rainfall intensity and the approximated loss by splash. Confrontation of values calculated in this way with direct measurements showed that splash loss sometimes amounted to 20 % of the gross applied rainfall intensity.

As soon as ponding arrived, the rain was stopped and the box was dried out from above by means of an electrical heater, till the weight of the box, and hence the mean water content of the sediment, was nearly reduced to its initial value. The exact weight was obtained by drying out at room temperature. The electrical heater was carefully used so that the surface temperatures of the artificial soil column never exceeded 55° C. The accurate application of this drying procedure not only permitted to start every experiment with the same mean water content of the sediment, but probably also led to comparable vertical water content variations with depth. The measurements are done for rains with $\beta = 20°$ and $\beta = 2.5°$. As stated above, S.T.O.R.M.-1 cannot produce artificial rains at β-values less than 4° or 5° when cinetic energy close to this of comparable natural rains is required. To obtain the value of $\beta = 2.5°$, the drum rotation velocity was reduced slightly below the necessary value. In this way, the mean cinetic energy was about 80 % from normal.

The graphs in figure 5 B show mass infiltrations for simulated rainfall intensities of ± 50 mm/h, deduced from the obtained infiltration envelopes. These data show two main points. First of all, there is a general trend to a decrease in mass infiltration with increasing slope inclination for both cases of slope inward and slope outward rains. Secondly, the graphs show local minimum values near to the points where the angle of drop incidence with the surface is close to 90°. It should be emphasised that these two characteristics are not restricted to the mass infiltration graphs for 50 mm/h, but that the same tendencies are found for all the other tested rainfall intensities. It can, therefore, be concluded that, for a given rainfall intensity, runoff generation times depend on two factors : slope inclination and angle of incidence of the raindrops.

It can be argued that the experiment, as carried out, is not very representative for field situations. A major objection could be the small dimensions of the area tested out. While there are reasons to believe that times to ponding in nature should be different from these in the experiment, it can be argued that when always using the same surface area, the trends of the graphs should be significant.

Concerning field situations in the study area of Rwanda, the graphs may indicate the spatial migration of the belt of runoff generation on a convex hill during a rainstorm. In the cases of slope outward rains, runoff should always generate first on the steepest hill sides, bordering the flat valley floors. When rain continues, the belt of runoff generation should shift upslope and finally arrive on the flat hill summit. In the case of slope inward rains, the phenomenon is more complex : an isolated runoff area higher up on the slope, can generate where ($\beta = - \alpha$) conditions are approached, before the belt of runoff generation arrived at this locality.

CONCLUSION

The simulation of artificial rain with a horizontal velocity component by S.T.O.R.M.-1 seems to add a new dimension to experimental research in the field of erosion processes. Although it is much too early to draw detailed conclusions as S.T.O.R.M.-1 and the first experiments certainly have their shortcomings, this first investigation undoubtedly shows that the orientation of rain, which has been neglected up till now should be taken into account. The experiments show, indeed, the existence of a definite influence of rainfall obliquity on processes such as splash-saltation and runoff generation. This has nothing to with the simple fact of uneven distribution of the amount of rainfall over slopes with different orientations. In the few cases described above, it is obviously the angle at which drops strike the surface, which is important. It is significant that even very slight rainfall obliquities with β values of 7.5 % and less have visible effects in the three studied cases. In the case of the splash experiment, splash transport has been demonstrated on a horizontal surface, and upslope directed net transport on slightly inclined slopes. The two other experiments show the influence of the angle of drop incidence with an inclined surface on the infiltration rate in pre-runoff and runoff conditions. All these data point to a possibly important impact from mean wind directions (i.e. mean rain directions) upon the intensity and even the nature of rain erosion processes acting on a slope. While factors as lithology, soils, vegetation, slope, and many others, are generally taken into account when studying erosion processes, in the field, rainfall obliquity, and especially the angle at which raindrops strike the slope seem to be wrongly neglected.

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