THE KINETIC ENERGY OF RAIN: APPLICATION ON SOIL EROSION

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1. INTRODUCTION

Our modern societies are increasingly concerned by the effects of extreme weather events. These phenomena occur more and more often and alarm the general public because of the important damages they may cause. Severe precipitation events in particular cause high economic losses and environmental disasters. Both problems converge in the case of soil erosion. From a meteorological perspective, the study of soil erosion by precipitation requires the knowledge of parameters such as drop size, precipitation volume, rain intensity, and above all the kinetic energy of the drops that hit the ground turning over and dislodging soil aggregates.

The present study is integrated in the EROSFIRE project (POCTI/AGR /60354 /2004), funded by the Portuguese Foundation for Science and Technology (FCT) with co-funding by FEDER through the POCI2010 Programme, which aims at developing a model-based tool for erosion hazard assessment following forest wildfires in Portugal. In this part the aim is determining soil sensitivity to erosion caused by rain after forest fires.

Splashing is considered the main factor in soil erosion because it is the first stage in erosion by water (Ellison, 1944). The impact of raindrops does not only modify the surface (Moss, 1991), but may also dislodge and release soil fragments that will later be carried to even very distant places if additional runoff processes occur at the same time (Moss and Green, 1983).

Splash erosion has often been studied in relation with the characteristics of rain, but less so than in the case of other causes of soil erosion because of the intrinsic difficulties associated to this phenomenon. A study on splash erosion will have to take into account not only the kinetic energy released by each storm, but also the variables type of soil and size of released particles (Sharma et al 1991), as well as the characteristics of the layer of water formed on the ground (Moss and Green, 1983, Kinnell, 1991, Leguédois et al., 2005). Because of these peculiarities, the studies carried out until now have been highly specific and it is difficult to extrapolate the results to larger areas that are not the study zone where the samples have been gathered (Van Dijk et al, 2002). However, there are studies that have attempted comparative analyses of soils with very different degrees of vulnerability (Terry, 1989).

This paper is an attempt to relate the energy released by rain to splash erosion making use of raindrop size and energy measured by means of an optical disdrometer. Raindrop size is used to calculate the volume, the terminal energy and the kinetic energy. Finally, the characteristics of the precipitation were compared with the mass of soil dislodged by splashing in two rain events in 2007.

2. STUDY ZONE

The data were gathered between the 22 May and the 30 September 2007 in Soutelo, Aveiro, Portugal (Fig. 1).

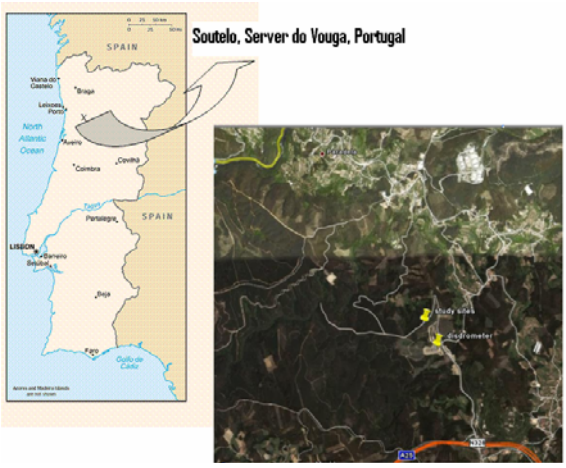

Fig. 1. Study zone close to Aveiro, Portugal.

In the study period occurred 91 rain events with a volume of more than 0.2 mm: 24 in May, 34 in June, 13 in July, 16 in August and 4 in September. All in all, the amount of rain collected was 258.2 mm, which contrasts with the typical climate in the region.

From a climatic perspective, the study zone belongs to an area of transition between the Atlantic and the Mediterranean climate zones, i.e., it is influenced by moist air masses from the Atlantic and also by strong winds. Consequently, very intense precipitation is relatively common in this region, even in inland areas.

The soil type is schist with cambisol and a franco-sandy texture. The vegetation in the area, which should serve as a first defense line against erosion, is formed almost exclusively by forests of *Eucalyptus globulus*, thus explaining the severe abrasions and landslides suffered in the area.

The vulnerability was increased by a moderate wildfire in August 2006 (one year before).

The study zone is part of the Erosfire international Project aiming at developing a GIS tool for surveying erosion in recently burned areas according to the different degrees of the slope.

3. MATERIALS AND METHODS

A Davis station was used to measure precipitation. This weather station lies 410 m

Fig. 2. Installing the optical disdrometer in Soutelo, Portugal.

above sea level (40º 40´48"N and 8º 20´31"W) and provided data on accumulated precipitation, pressure, wind speed, wind direction and temperature.

In addition, an optical disdrometer of the Thies model (Fig. 2) was used. This tool is described in Bloemink and Lanzinger (2005) and registers raindrop size spectra every minute.

The range of the disdrometer measures droplets with diameters between 0.125 mm and 8 mm.

The equipment used to carry out this study on erosion is represented in Fig. 3 and 4, including diagrams and pictures of the models that will be called here *Terry* (Fig. 3) and *Cup* (Fig. 4), installed 3 cm above the ground. Both models have simple designs, both are cheap and easy to build, and their main advantage is the fact that once installed the paper filters may be removed without taking the devices apart or altering the surface in any way. So the loss of soil is calculated by measuring these filters, after drying into oven, both before and after the field.

The *Terry* model, based on the design by Terry (1989), is formed by two funnels with some space in between to insert a filter to gather the soil released. The sampling range is of 12 cm. The two-funnel system ensures that the soil particles captured by the device will not be lost again as it protects the filter from washout.

The *Cup* model is based on an original design by Poesen and Torri (1988), later

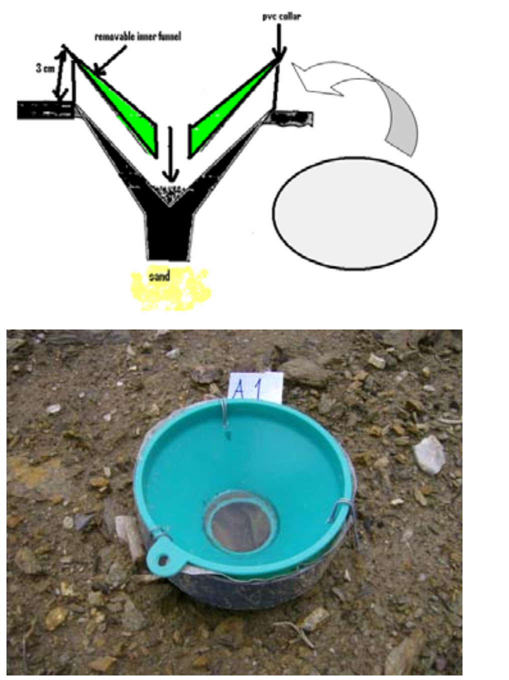

Fig. 3. Structure of the *Terry* model. Picture of a *Terry* ready to register splashings.

Fig. 4. Structure of the *Cup* model. Picture of a *Cup* ready to register splashings.

modified following Molina and Llinares (1996). It consists of a 7 cm long aluminum cylinder with a diameter of 10 cm. Inside this cylinder is fixed a 0.5 cm opening wire mesh. The filter is secured on top of the mesh, and on top of the filter is fixed another mesh, this time a movable one with a much larger opening. The aim is to reduce the likelihood of the raindrops washing out the filters that have already collected samples of splashed soil particles. The device is fixed to the ground with legs instead of with long cylinders to avoid runoff water swirling down the slope and contaminating the filters with dragged and not splashed soil particles.

4. KINETIC ENERGY OF RAIN

The information provided by the disdrometer was used to calculate the kinetic energy of rain: drop size distribution (DSD). This piece of data is used to calculate the mass of each drop and its fall velocity (Ryzhkov et al 1999). It is necessary to know the shape of the drop in order to calculate its mass.

The shape of raindrops has been the focus of several studies (Brandes, 2002, Sansom, 2004). The main conclusion of these studies is that drops smaller than 1 mm are spherical, whereas drops with diameters larger than 1 mm have more of an ellipsoid shape. Beard et al. (1989) established index α = vertical measurement / horizontal measurement. For raindrops with a diameter d= 1 mm, $\alpha = 0.98$, but for $d > 5$ mm, $\alpha < 0.7$).

The studies carried out by Jones (1959), Brook and Latham (1968) and Chandrasekar et al. (1988), among others, have contributed to solve the problem, and the studies by Beard and Chuang (1987) and Park, et al (2004) have provided the following criterion: it will be assumed that raindrops are spherical if they are smaller than 1 mm in diameter; in the case of raindrops smaller than 1.075 mm the calculations by Brandes et al. (2002) were applied. From that size on a polynomial equation of degree 12 was calculated. The result is shown in Fig. 5, together with the volume calculated assuming that all drops are spherical.

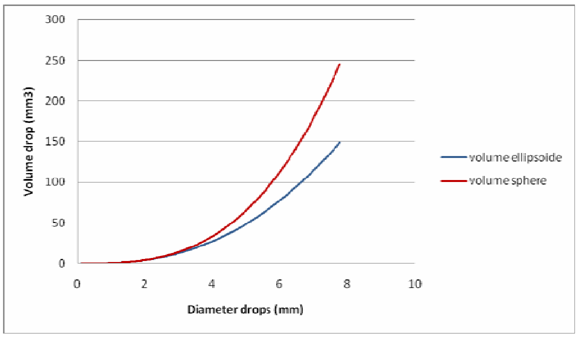

Fig. 5. Relationship between the drop size measured by the disdrometer and its volume. It may be compared with the volume of the supposedly spherical drop.

The mass and the velocity need to be known for calculating the kinetic energy. The dated studies by Gunn and Kinzer (1949) are still useful due to the fact that the results are based on experimental measurements. These are taken into consideration in this paper. The measurements were limited to sizes between 0.125 and 5.8 mm, and do not reach values of 8 mm, which our disdrometer measures. Even though such large drops rarely appear, the need to count on a relationship between the velocity and the diameter in the whole interval led us to extrapolate the results and achieve a good fit for the entire range of measurements by Gunn and Kinzer (1949). The results are listed in Fig. 6.

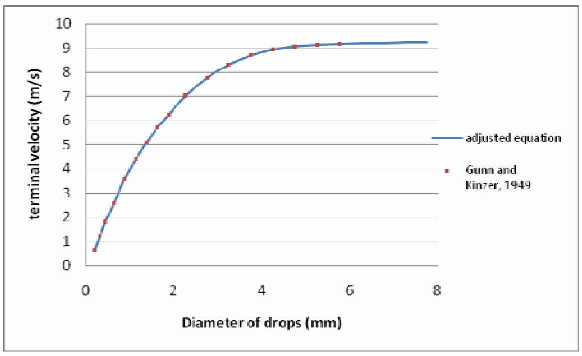

Fig. 6. Relationship between the drop size measured by the disdrometer and their terminal velocity.

In each of the size channels of the disdrometer the kinetic energy was calculated as the mean value of the kinetic energies corresponding to the two extremes of the channel.

5. RESULTS AND CONCLUSIONS

Figure 7 shows the DSD data at Soutelo during the study period. A practically exponential distribution is observed except in the case of large sizes. Fig. 7 also presents the total kinetic energy by unit of area of the rain registered in the study period. The data show that drops in the interval between 2 and 2.5 mm are the greatest contributors to the kinetic energy that hits the ground.

The two devices used for measuring splash erosion were installed in two different periods: one from 23 July to 6 August, and the other from 6 August to 27 August 2007. Figure 8 shows the characteristics of drops in those two periods. Figure 9 presents details (minute by minute) of the energies registered over 4 hours on the first rain day. This provides data on the evolution of energy in time.

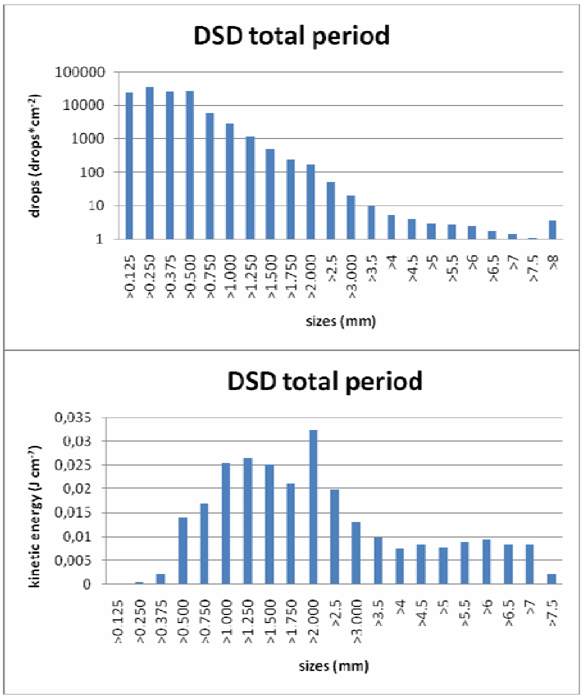

Fig. 7. Drop size distribution and energy distribution by drop size during the sampling period.

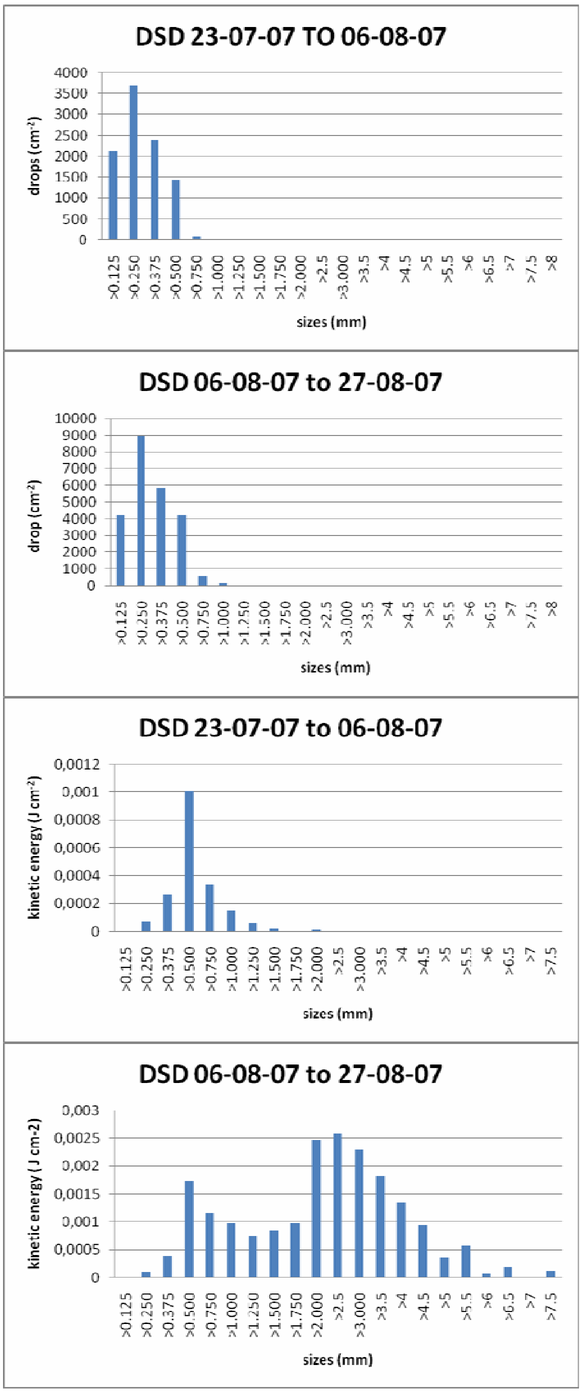

Fig. 8. Drop size distribution and energy distribution by drop size during the two rain periods with splash erosion samplings.

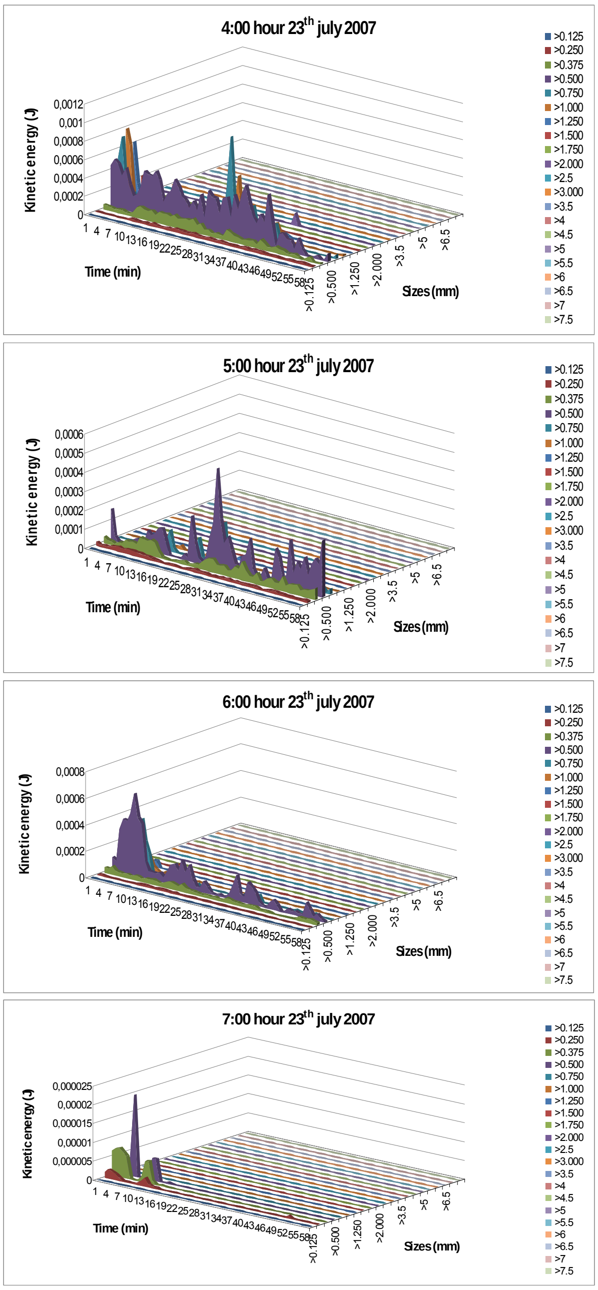

Fig. 9. Energy distribution, minute by minute, by drop size during 4 hours on 23 July 2007.

Figures 7-9 provide the necessary information to calculate the total energy of the rain in the two different sampling periods. The result is 0.0019 J/cm² in the period between 23 July and 6 August and 0.020 J/cm² in the period between 6 and 27 August.

Finally, Fig. 10 shows the amount of soil that was splashed as measured by the two devices, *Terry* and *Cup,* during the two rain periods.

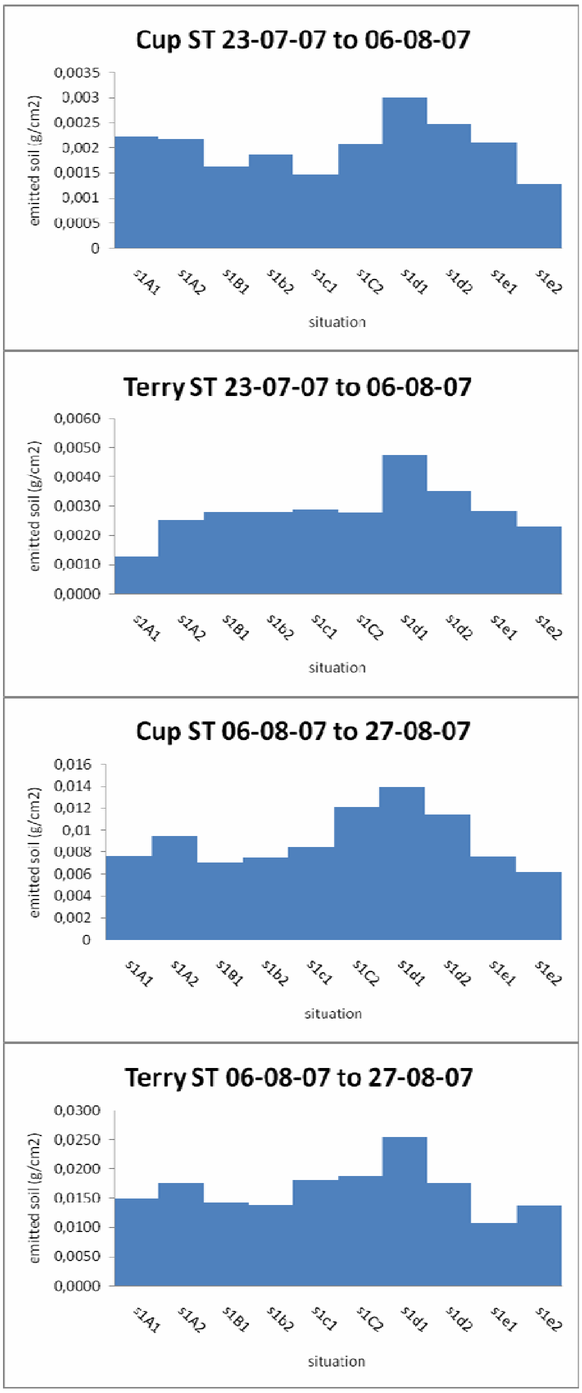

Fig. 10 Mass of soil splashed by rain in the two rain periods as measured by *Cup* and *Terry*. The identifiers of each device appear on the axis of abscissas.

Figure 10 shows that the two measuring devices offer different results. The mean

Table 1. Mean value and standard deviation of the mass of soil splashed (in g/cm³) in each rain period.

	23-VII a 6-VIII	6-VIII a 27-VIII
Terry	0.0029 ±0.0009	0.017 ±0.004
Cup	0.0020 ±0.0005	0.009 ±0.003

values and the standard deviation are presented in Table 1.
The Terry gives higher estimates than the cups and this is in line with the fact that the Terry was specifically designed to avoid blow out.
The results pointed out above, together with the comparison of the values in Table 10 with the total kinetic energy in each rain period, enable us to draw the following conclusions:

- The correction of the drop volume because of the fact that they are not spherical represents up to 50% of its value or more, which leads to the same relative error in the kinetic energy calculated. With ordinary drop sizes (smaller than 4 mm), the error may lie under 15%.
- The DSD of the precipitation in Aveiro follows an exponential or gamma distribution. The energy distribution, however, is gamma.
- The *Terry* and *Cup* devices provide different results when measuring the soil splashed by rain, but more data are needed to establish general principles on the goodness of the measurement.
- In any case the two devices point towards the fact that the kinetic energy of rain is an important factor in splash erosion and that erosion increases with an increase in the kinetic energy.
- The mass of soil affected by splash erosion is not directly proportional to the kinetic energy of rain.

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