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Simulated raindrop's characteristic measurements. A new approach of image processing tested under laboratory rainfall simulation

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ABSTRACT

The size of the drops determines soil erosion and runoff rates, and then the fate of ecosystems. Various raindrop measurement techniques and tools have been developed to determine natural and simulated raindrop size distributions and mean drop size. There is a need to improve the procedure to determine the raindrop properties, and this is why we develop a new technique to analyze drop size distribution and fall velocity. For this purpose a rainfall simulator with two oscillating Veejet 80100 nozzles in laboratory condition, and high speed imaging technique and edge detection approach in image processing was applied to identify and measure drop size and calculate drop velocity. The results showed that the rainfall simulator was able to create drops with diameter in the range from 0.2 to 9.9 mm. Fall velocity ranged from 0.8 to 9.2 m/s for different diameter classes in the height of 0.5 m above the ground. The results indicate that the low-cost technique developed in this paper had high ability to automatically and rapidly identify raindrops characteristics with high accuracy. This technique can help to calibrate other rainfall simulators, but also to characterize natural rainfall events in different regions, which is a worldwide need due to the lack of information, and the importance of the raindrop characteristic to characterize and model the soil erosion processes.

1. Introduction

Rainfall drop sizes determine the hydrological and erosional responses of soils and then the fate of the ecosystems (Keesstra et al., 2009; García-Ruiz et al., 2017). This is relevant in bare landscapes where the raindrop impact creates surface morphologies and detaches soil particles (Vaezi et al., 2017). Badlands (Martínez-Murillo et al., 2013; Ferrer et al., 2017) and agriculture land (Masselink et al., 2017) are the most affected landscapes. Soil erosion is determined by the erodibility of the soils (Keesstra et al., 2016a; Kavian et al., 2017) and the erosivity of the rainfall (Kavian et al., 2011; Mohammadi and Kavian, 2015; Rodrigo-Comino et al., 2016a). In order to quantify the rainfall erosivity the drop size is the key factor, then any advance with the method to determine drop sizes will end in a relevant advance in the scientific knowledge of the soil system (Rodrigo-Comino et al., 2018a, 2018b). This is a relevant contribution to the sustainability of the soils such as the United Nations show in the Goals for sustainability (Keesstra et al., 2016b), and also to the sustainable use of the water, soil and biota (Keesstra et al., 2012; Mol and Keesstra, 2012; Mekonnen et al., 2017). To determine the drop size under natural rainfall will be very useful, and the use of rainfall simulators will contribute to calibrate the method and allow the use of repetitions such has been done previously where the rainfall simulation was found a very successful technique (Cerdà and Jurgensen, 2011; Lassu et al., 2015; Safari et al., 2016; Rodrigo-Comino et al., 2016bb; Cerdà et al., 2017a, 2017b).

Rainfall simulator generally provides a more rapid, efficient, controlled, and adaptable rainfall (Meyer and Harmon, 1978; Kavian et al., 2014; Rodrigo-Comino et al., 2016bc). So, numerous types of rainfall simulators have been widely used to study the hydrological processes, soil erosion and sediment transfer (Iserloh et al., 2013a, 2013b; Cerdà et al., 2017a, 2017b; Kirchhoff et al., 2017; Rodrigo-Comino et al., 2017). Whereas drop formers are the key component in rainfall simulators, researchers have been focusing on raindrop size and velocity as important criteria for more accurately storm simulation (Sadeghi et al., 2013). Various raindrop measurement techniques and tools broadly categorized into manual and automated techniques to determine simulated raindrop size distributions and mean drop size (Kathiravelu et al., 2016). Manual techniques were used in early studies (Wiesner, 1895), the stain method (Hall, 1970; Kincaid et al., 1996; Sadeghi et al., 2013), the flour method (Laws and Parsons, 1943; Kohl and DeBoer,

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1984; Ries and Langer, 2001; Parsakhoo et al., 2012; Sadeghi et al., 2013), the momentum method (Scheleusener, 1967), the submersion technique (Gunn and Kinzer, 1949; Eigel and Moore, 1983), the photography method (Hoffman, 1977; Kinnell, 1984; Mc Isaac, 1990), the optical array probe (Swithenbank, 1977; Chigier, 1991), the image processing technique (Sudheer and Panda, 2000; Salvador et al., 2009; Abudi et al., 2012), the radar technique (Chandrasekar and Bringi, 2001; Bringi et al., 2003) and the disdrometer (Nystuen, 1999; Salmi and Ikonen, 2005; De Moraes Frasson et al., 2011). Are all examples of methods that provide measurements of the number and size of raindrops. The disdrometer method has been the most successful one during the last decade due to the capability to develop a large amount of measurements (Fernández-Raga et al., 2009; Fraile et al., 2013) and it is very efficient to measure the role the raindrop impact plays in splash detachment (Fernández-Raga et al., 2017) and on soil erosion due to the soil cover changes (Rodrigo-Comino et al., 2017; Keesstra et al., 2018).

According to the opinion of the users, stain method, flour and oil immersion techniques are time consuming and record data temporarily. Also, the photographic method (Hoffman, 1977) can provide a direct measurement to determine the size of individual drops. However, visual interpretation is limited by the ability of the eye to discern total values on an image, and the difficulty for an interpreter to simultaneously analyze numerous spectral patterns are considered as the sources of error (Sudheer and Panda, 2000), meanwhile automatic sampling devices provided continuous records have the disadvantage of being costly, complicated to manage and inconvenient for routine use (Jayawardena and Rezaur, 2000). The most advanced techniques are the optical disdrometer (Grossklaus et al., 1998), the 2D-video disdrometer (Schonhuber et al., 1995) and the Joss-Waldvogel rainfall disdrometer supply data continuously (Kinnell, 1976) as they were primarily designed for meteorological studies to provide a completely automatic records. So, they are too sophisticated and, at the present time, too expensive for routine studies of soil erosion (Jayawardena and Rezaur, 2000). Besides, these devices have specific sources of errors such as those induced by side-passing drops and overlapping drops (Salvador et al., 2009). Also, Burguete et al. (2007) analyzed the use of the disdrometer to estimate drop velocity from drop time of passage. They found it subjected to large experimental errors due to overlap of raindrop impacts.

Image processing is the enterprise of automating and integrating a wide range of processes and representation used for vision perception (Sudheer and Panda, 2000). This technique based on computer vision can be used to obtain data sets adequate for detail analysis and consists of three steps of data acquisition, processing and interpretation. This method does not require to the calibration and the accuracy of the measurement depends on the type of camera (Abdollahi et al., 2011) and depth of image background (Chigier, 1991; Nishino et al., 2000).

Sudheer and Panda (2000) applied digital image processing technique to determine the drop size distribution from an irrigation spray nozzle and reported that image processing technique can be successfully implemented for accurate drop size measuring. Salvador et al. (2009) used low-speed photos to provide information on drop diameter, velocity and angle of each simulated drop. They claimed that the proposed technique estimate drop diameter, velocity and angle through direct measurements, and guarantee quality in the characterization of the drops present in the photographs. They reported that the diameter and velocity measurements were successfully validated and the photographic technique is free from some of the problems of optical methods. Covert and Jordan (2010) used a digital camera that captured drops on a grid screen in order to analyze simulated droplet size distribution. The droplet diameter was measured from the range of 0 to 6 mm.

Abdollahi et al. (2011) also used image-processing technique to select the best performance nozzles in a rainfall simulator. They calculated median diameter, velocity and impact angle to 1.4 mm, 4.6 m/s and 89°, respectively. Abudi et al. (2012) applied a high frame-rate camera capable of capturing 8000 frames per second for monitoring the simulated falling drops and calculating their velocity and size. In their research, the drop diameter ranged from 1 to 5.2 mm and the median diameter was 1.5 mm. They also reported that the average of diameter obtained in this method is very close to stain method. Sadeghi et al. (2013) recorded raindrops at several intensities in Mazandaran Province using Canon EOS 550D camera capable of recording 4000 frames per second. For image processing they omitted the droplets located out-of-focus of the camera lens from the dataset in order to enhance the measurement accuracy. They calculated droplet diameter from the range of 0.2 to 6 mm and also they reported that results obtained from flour method and photography technique was rather similar. Cerdà et al. (1997) used the photography technique to measure the speed of the drops, but the size was determined by other methods such as the flour one.

The current study aims to introduce a fast and accurate approach for measuring raindrop diameter and fall velocity for simulated rainfall based on image processing technique. Different pressures were used in the rainfall simulator to assess the methods under different drop sizes.

2. Materials and methods

2.1. Rainfall simulator description

The designed rainfall simulator was settled on an A-frame metal structure at a height of from 2 to 2.7 m. The telescopic and adjustable legs (35 mm of diameter) are appropriated for sloping terrain and can reach 4 m in height in the field if necessary. Two movable Veejet 80100 nozzles with the aperture diameter of 4.5 mm are used here. Those nozzles are widely use on forest and agriculture land. Here, our calibration is developed under laboratory conditions. A metal cube was located under each nozzle for returning excess water to the pumping system. Besides, a flexible hose with the diameter of 15 mm which connected to an electric pump was settle for pumping water to nozzles. Water flow was transferred into nozzles located at a height of 2 m with equal pressure using a metal divider and two hoses with the length of 70 cm. The water pressure flowing in the hoses was monitored by a manometer (0–160 kPa). The pressure and flow rate was controlled using a valve installed in water supplying pipe. Also, a control board was designed to programme ten different rainfall events. This control board can set nozzles velocity fluctuation, precipitation duration from 1 min to 1 h and oscillation angle of nozzles from 0° to 60° (Fig. 1).

2.2. Data acquisition

Photographs of raindrops were taken using a digital high resolution, high-speed camera (Nikon D90, 12.9 Megapixel) capable of recording 4000 frames per second to determine raindrop size. The optimum focal distance of the camera was 35 mm. A wooden frame (55 × 33 cm) with a 3 × 3 cm board fixed in its center as the focal plane was installed under at a height of 0.5 m above the ground level (Sadeghi et al., 2013). The pictures were done by zooming on the center of the frame. A recorded image of simulated raindrops is shown in Fig. 2. All photos were taken at the pressures of 20, 40, 60 and 80 kPa to compare raindrop size distribution under different operating pressures, which results in different raindrop sizes. This is necessary to test the quality and accuracy of the technique, to calibrate the rainfall simulator and to test that the methods and apparatus used are suitable to characterize the raindrop characteristics.

2.3. Processing and interpretation

We used Imagej (Version 1.46r) software for image processing and measuring simulated raindrop size. Imagej is a public domain, Java-based image processing program developed at the National Institutes of Health (Collins, 2007; Schneider et al., 2012). This software supports