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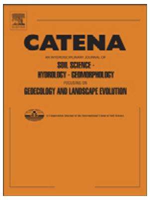

European small portable rainfall simulators: A comparison of rainfall characteristics

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ABSTRACT

Small-scale portable rainfall simulators are an essential research tool for investigating the process dynamics of soil erosion and surface hydrology. There is no standardisation of rainfall simulation and such rainfall simulators differ in design, rainfall intensities, rain spectra and research questions, which impede drawing a meaningful comparison between results. Nevertheless, these data become progressively important for soil erosion assessment and therefore, the basis for decision-makers in application-oriented erosion protection.

The artificially generated rainfall of the simulators used at the Universities Basel, La Rioja, Malaga, Trier, Tübingen, Valencia, Wageningen, Zaragoza, and at different CSIC (Spanish Scientific Research Council) institutes (Almeria, Cordoba, Granada, Murcia and Zaragoza) was measured with the same methods (Laser Precipitation Monitor for drop spectra and rain collectors for spatial distribution). Data are very beneficial for improvements of simulators and comparison of simulators and results. Furthermore, they can be used for comparative studies, e.g. with measured natural rainfall spectra. A broad range of rainfall data was measured (e.g. intensity: 37–360 mm h^{-1}; Christiansen Coefficient for spatial rainfall distribution: 61–98%; median volumetric drop diameter: 0.375–6.5 mm; mean kinetic energy expenditure: 25–1322 J m^{-2} h^{-1}; mean kinetic energy per unit area and unit depth of rainfall: 0.77–50 J m^{-2} mm^{-1}). Similarities among the simulators could be found e.g. concerning drop size distributions (maximum drop numbers are reached within the smallest drop classes <1 mm) and low fall velocities of bigger drops due to a general physical restriction. The comparison represents a good data-base for improvements and provides a consistent picture of the different parameters of the simulators that were tested.

1. Introduction

Rainfall simulation has become an important method for assessing the subjects of soil erosion and soil hydrological processes. It is an essential tool for investigating the different erosion processes *in situ* and in the laboratory, particularly for quantifying rates of detachment and transportation of material (e.g. Cerdà, 1999). Its application allows a quick, specific and reproducible assessment of the meaning and impact of several factors, such as slope, soil type (infiltration, permeability), soil moisture, splash effect of raindrops (aggregate stability), surface structure, vegetation cover and vegetation structure (Bowyer-Bower and Burt, 1989; Schmidt, 1998). The possibility of high repetition rate offers a systematic approach to address the different factors that influence soil

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erosion even in remote areas and in regions where highly erosive rainfall events are rare or irregular. A compilation of different rainfall simulator systems is given by Meyer (1988) and Hudson (1995). Cerdà (1999) reports on the history of rainfall simulation over the past 62 years and lists 229 different simulators by author, year of construction, application by country, nozzle type, capillary material, drop diameter, precipitation intensity, plot size and research question.

The need to distinguish the different partial processes of runoff generation and erosion led to the development of rainfall simulations on small plots (Calvo et al., 1988). The advantages of small portable rainfall simulators are, among others, the low costs, the easy transport in inaccessible areas and the low water consumption. Small portable rainfall simulators also enable data to be obtained under controlled conditions and over relatively short time periods. They have been used worldwide by different research groups for many years. Since 1938 more than 100 rainfall simulators with plot dimensions <5 m^2 (most of them <1 m^2) were developed (e.g. Abudi et al., 2012; Adams et al., 1957; Alves Sobrinho et al., 2008; Battany and Grismer, 2000; Birt et al., 2007; Blanquies et al., 2003; Bork, 1981; Bryan, 1974; Calvo et al., 1988; Cerdà et al., 1997; Clarke and Walsh, 2007; De Ploey, 1981; Farres, 1987; Hudson, 1965; Humphry et al., 2002; Imeson, 1977; Kamphorst, 1987; Loch et al., 2001; Luk, 1985; Martínez-Mena et al., 2001a; Medalus, 1993; Nadal-Romero and Regüés, 2009; Neal, 1937; Norton, 1987; Poesen et al., 1990; Regmi and Thompson, 2000; Regüés and Gallart, 2004; Roth et al., 1985; Torri et al., 1999; Wilm, 1943). There is no standardisation of rainfall simulation and these rainfall simulators differ in design, rainfall intensities, spatial rainfall distribution, drop sizes and drop velocities, which impede drawing a meaningful comparison between results. Nevertheless, the data have become progressively important for soil erosion assessment and decision-making in application-oriented erosion protection. Therefore, the accurate knowledge of test conditions is a fundamental requirement and is essential to interpret, combine and classify results (Boulal et al., 2011; Clarke and Walsh, 2007; Lascelles et al., 2000; Ries et al., 2013).

A summary of major requirements for small portable rainfall simulators is given in Iserloh et al. (2012). The most substantial and critical properties of a simulated rainfall are the drop size distribution (DSD), the fall velocities of the drops and the spatial distribution of the rainfall on the plot-area. Since the 1970s, published studies have shown variations in these properties generated by respective simulators (e.g. Cerdà et al., 1997; Fister et al., 2011, 2012; Hall, 1970; Hassel and Richter, 1988; Humphry et al., 2002; Iserloh et al., 2012; Kincaid et al., 1996; King et al., 2010; Lascelles et al., 2000; Ries et al., 2009; Salles et al., 1999; Zhao et al., 1996). Many techniques were used to characterise simulated rainfall, such as the flour pellet method (Hudson, 1963; Laws and Parsons, 1943), laser particle measuring system (Salles and Poesen, 1999; Salles et al., 1999), plaster micro plot (Ries and Langer, 2001), indication paper (Brandt, 1989; Cerdà et al., 1997; Salles et al., 1999; Wiesner, 1895), Joss-Waldvogel Disdrometer (Hassel and Richter, 1988; Joss and Waldvogel, 1967) and the oil method (Gunn and Kinzer, 1949) among others. It was shown that the results of the characterisation of simulated rainfall were extremely dependent on the particular method that was applied (Ries et al., 2009). Against this backdrop, a standardized method for verifying and calibrating the characteristics of simulated rainfall is paramount, and the Laser Precipitation Monitor (LPM) represents the most up-to-date and accurate measurement technique for obtaining information on drop spectra and drop fall velocities (King et al., 2010; Ries et al., 2009), along with an optimal price-performance ratio. Quantity and spatial distribution of the simulated rain can be easily measured with rain-collectors (covering the complete testplot) at low cost and good performance.

In this study, artificial rainfall generated by 13 rainfall simulators based in various European research institutions from Germany, the Netherlands, Spain and Switzerland was characterised using LPM and rain collectors in all simulations in order to ensure comparability of the results. The studied rainfall simulators represent most of the devices that have been used in Europe over the last decade and they present a wide range of designs, plot dimensions (0.06 m^2 up to 1 m^2), numbers and types of nozzles and rainfall intensities. The main research question to be answered is: What are the most important differences/similarities in the suite of simulated rainfall characteristics investigated?

2. Material & methods

2.1. Rainfall simulators

The 13 small portable field rainfall simulators that were tested are shown in Fig. 1 and their main characteristics are listed in Table 1. The simulators are three new developed prototype nozzle-type simulators based at Tübingen (TU), Cordoba (CO) and Basel (BA) as well as two capillary-type simulators from Granada (GR) and Wageningen (WA). The eight other simulators are round plot nozzle-type simulators based at Almeria (AL), Malaga (MA), Murcia (MU), Trier (TR), Zaragoza-CSIC (ZAC), Valencia (VA), Zaragoza-University (ZAU) and La Rioja (LR), and their design follows Calvo et al. (1988) and Cerdà et al. (1997). This round plot type of rainfall simulator is the most common device used in semi-arid areas in Europe, especially in Spain, and major differences typically occur in pumps, nozzles and applied intensities. Duration of all simulators is adjustable, only the WA-simulator is limited to three min, due to its compact design.

2.2. Methods for evaluating rainfall characteristics

2.2.1. Drop size distribution and drop fall velocities

The Thies Laser Precipitation Monitor (LPM) was used for analysing the DSD and drop fall velocities. LPM measures the amount and intensity of rainfall and determines raindrop size and velocity as the drops fall through a laser beam (area of 46 cm^2 (23 x 2 cm)). It registers individual drops with diameters ranging from 0.16 mm to 8 mm, and fall velocities ranging from 0.2 m s^{-1} to 20 m s^{-1}, up to a maximum intensity of 250 mm h^{-1} (Thies, 2004). A more detailed description of the LPM is given in Angulo-Martínez et al. (2012), Fister et al. (2012), King et al. (2010) and Scholten et al. (2011). Because the LPM records only drop size and drop velocity classes, we used the mean value of each class to calculate kinetic energy, momentum and median volumetric drop diameter (d_{50}).

2.2.2. Spatial rainfall distribution

In order to generate quantitative information about the homogeneity and the reproducibility of rainfall, small rainfall collectors were used to measure the spatial rainfall distribution. The entire test plot was covered by collectors: square ones (56 cm^2; in case of Basel: 100 cm^2) for square plots and round collectors (20 cm^2) for round plots (Fig. 2).

2.3. Test procedure

A standardized test procedure was developed and performed with the simulators.

Prior to each test sequence, rainfall intensity was calibrated using the method generally applied by each group to maintain the customary rainfall conditions of their experimental work. TR and VA used a calibration plate covering the whole plot, TU used the LPM technique, and the remaining groups used rain collectors.

Water discharge of nozzles was determined using the volumetric method.

In order to analyse drop spectra with the LPM, five representative positions within the total plot area were chosen (Fig. 2). At each position, five replications at one minute measurement intervals were performed (except the WA-simulator whose design allows only a