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Preliminary study on mechanics-based rainfall kinetic energy

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Abstract

A raindrop impact power observation system was employed to observe the real-time raindrop impact power during a rainfall event and to analyze the corresponding rainfall characteristics. The experiments were conducted at different simulated rainfall intensities. As rainfall intensity increased, the observed impact power increased linearly indicating the power observation system would be satisfactory for characterizing rainfall erosivity. Momentum is the product of mass and velocity (Momentum=MV), which is related to the observed impact power value. Since there is no significant difference between momentum and impact power, observed impact power can represent momentum for different rainfall intensities. The relationship between momentum and the observed impact power provides a convenient way to calculate rainfall kinetic energy. The value of rainfall kinetic energy based on the observed impact power was higher than the classic rainfall kinetic energy. The rainfall impact power based kinetic energy and the classic rainfall kinetic energy showed linear correlation, which indicates that the raindrop impact power observation system can characterize rainfall kinetic energy. The article establishes a preliminary way to calculate rainfall kinetic energy by using the real-time observed momentum, providing a foundation for replacing the traditional methods for estimating kinetic energy of rainstorms.

Key Words: Kinetic energy, Impact, Momentum

1 Introduction

Soil erosion by water is the result of soil detachment and transport by rainfall and runoff. Soil loss from small plots has been related to the product of rainfall kinetic energy (*E*) and the maximum 30 minute rainfall intensity (*I*) within a storm (Wischmeier and Smith, 1958) and is the rainfall parameter (*EI*) used to estimate soil erosion in the Universal Soil Loss Equation (Wischmeier and Smith, 1978).

To measure the rainfall characteristics needed to calculate *E* is expensive and difficult. A technology that could directly measure *E* would greatly add to the ability to do soil erosion research using both natural and artificial rainfall.

A number of empirical relationships between kinetic energy and rainfall intensity have been developed (Zheng et al., 2009; Wischmeier and Smith, 1958; Rosewell, 1986; Uijlenhoet et al., 1999; Bogen et al., 1992; Salles et al., 2002; Carter et al., 1974). However, it is difficult to extend those empirical relationships to different regions due to differences in the methods of measurement, sample size of the studies, type of sampling, and errors and uncertainty (Sanchez-Moreno et al., 2012). A reliable way to measure rainfall energy directly is important for future soil erosion studies.

Scientists have developed high sensitivity recorders and high precision instruments, such as a photoelectric raindrop size spectrometer (Mason et al., 1953), balloon-borne instruments and instruments using the wind tunnel principle (described in Mason, 2010), Joss-Waldvogel rainfall disdrometer (Kinnell, 1976), force transducer (Jayawardena et al., 2000), and others.

Jayawardena and Rezaur (2000) have introduced an approach using a piezoelectric force transducer to find

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raindrop size distribution, momentum, and kinetic energy of rainfall at raindrop impact. To establish the rainfall kinetic energy-intensity and rainfall momentum-intensity relationships, Sanchez-Moreno et al. (2012) introduced an optical laser disdrometer. Both of these instruments were applied to measure single raindrop energy. Applying such instruments across a wide intensity range and the range of local weather, including wind, presently requires a considerable effort to calculate the kinetic energy of rainfall.

The objective of this study is to develop and test a system to measure rainfall kinetic energy directly.

2 Materials and methods

2.1 *Raindrop impact power observation system*

The raindrop impact power observation system was developed by the Nanjing Institute of Soil Science, Chinese Academy of Sciences (Yang and Liang, 2010). It is a real-time raindrop impact force observation system which contains three elements (Fig.1): a measuring terminal (outdoor section), a control box (indoor section), and a computer terminal (indoor section).

The core innovation in the system is in the design of the measuring terminal. The measuring terminal contains a rain cover (50 cm×50 cm), a support structure, rotation axis, transducer, amplifier, spacer, level bubble, base plate, and bolt supporting feet.

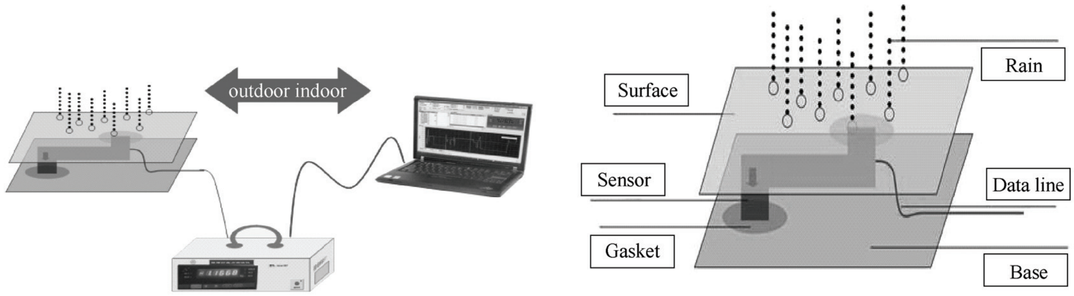

Fig.1 Diagram of the structure of the raindrop impact power device

The core component of the instrument is a raindrop induction sensor, which is a strain gauge load cell. Under the action of an external force, the elastomer generates elastic deformation, which causes deformation of a strain gauge which is adhered to the surface of the elastomer. When deformation of the strain gauge occurs, the resistance value changes. This resistance change is converted to electrical signals (voltage or current) completing the transformation of the external force to an electrical signal. The measuring terminal component, with its core transducer, and a single chip to display and control instruments and storage systems, constitutes the complete raindrop impact power observation system. The instrument can measure the raindrop impact force (F, kg m s^{-2}) on a unit area in a short interval, with a sampling frequency of 1 to 500 times per second. The system is capable of displaying and recording the complete series of measurements for an entire rainfall event.

2.2 *Rainfall simulation laboratory*

The experiment was conducted in the rainfall simulation laboratory in Nanjing Forestry University. The rainfall simulation system is made up of a power system, control systems, and a piping system. The spray nozzle system is a combination of three kinds of vertical spray nozzles (Fulljet 1/8, 2/8, 3/8) made by Spraying System Corporation, which stack into a raindrop injection group. Nozzle specifications are “FULLJET1/8, 2/8, 3/8”. The nozzle pressure is controlled by a transducer for accurate control of nozzle flow rates.

The chosen nozzle produces drop sizes and distributions near those of natural rainfall. The effective rainfall area is 5 m×6 m， and the nozzle heights are up to 6 m. Due to the height of the simulator and the initial velocity of drops from the nozzle, the drops are at terminal velocity when they impact the test area. Uniformity of rainfall is greater than 90% over the entire test area. The angle of impact of the drops from the nozzle is vertical. The computer-driven system creates reproducible storm patterns that can be varied over arange of intensities from 5 to 150 mm h^{-1}.

2.3 *Experimental procedure*

A rain gauge which measured rainfall intensity directly was located adjacent to the measuring terminal.