ESTIMATING RAINDROP KINETIC ENERGY: EVALUATION OF A LOW-COST METHOD

J. Wang, D. B. Watts, Q. Meng, T. R. Way, Q. Zhang

ABSTRACT. *The Loess Plateau of China is regarded as the most intensively eroded region in the world and soil erosion caused by raindrop impact is a common occurrence on agricultural land within this region. Therefore, understanding the influence of rainfall energy on the soil surface is needed to improve prescriptions for best management practices aimed at mitigating erosion. Disdrometers for measuring rainfall energy are presently available; however, these are relatively expensive and their use may not be justified for determining raindrop energy for predictive soil erosion models in regions where there are limited economic resources. To overcome this constraint, a device was tested for evaluating size and velocity of water drops during rainfall events. This device utilized two rotating disks combined with filter paper to obtain raindrop diameter and velocity which can then be used for determining the kinetic energy of falling raindrops. With this device, raindrop diameter was determined from the resultant raindrop stain left on the filter paper during rainfall events and velocity was calculated from the time it took a falling raindrop to travel between the pair of rotating disks. Measurements were taken for approximately 10 minutes during each of six rainfall events of different intensities over a three month period (from June to August of 2013). The smallest raindrop measured was 0.39 mm diameter and the largest was 5.92 mm diameter. The event average raindrop diameter increased with increasing event rainfall intensity. The minimum raindrop impact velocity was 1.47 m s^{-1}, the maximum was 9.45 m s^{-1}, and the event average terminal velocity increased as event rainfall intensity increased. Estimated raindrop kinetic energy ranged from 0.04×10^{-6} J to 4728.21×10^{-6} J, with event mean raindrop kinetic energy ranging from 40.33×10^{-6} J to 276.94×10^{-6} J. The relationship between estimated event rainfall kinetic energy and event rainfall intensity was represented by an exponential function. The disk device was also compared to an optical disdrometer. The data collected for rainfall intensity, raindrop diameter, and velocity were statistically similar between the two devices. Results from this study show that this low-cost method can be used to estimate rainfall kinetic energy in the Loess Plateau region of Northwest China.*

Keywords. *Loess Plateau, Raindrop diameter, Raindrop velocity, Rainfall intensity.*

Soil erosion is one of the primary causes of land degradation worldwide, negatively impacting agricultural production. For instance, erosion depletes the soil of critical nutrients, thereby adversely affecting its ecological functions for food production, water infiltration, and C and N storage (Blum et al., 2006). Intensive agrarian practices that utilize tillage and leave the soil bare and devoid of vegetation have played an integral role in exacerbating erosion (Meijer et al., 2013). As a result, effort is being made to evaluate erosion processes and to develop practices that minimize their detrimental effects.

Marsh and Grossa (2005) define soil erosion as the dislodgement of particles from soil by water or wind, subsequently redepositing the sediments elsewhere. Soil erosion by wind and water accounts for about 84% of all degraded land worldwide, with Asia presently being one of the most erosion-prone continents (Osman, 2014). Of the land degraded from erosion, approximately 56% has occurred by erosive action of water (Osman, 2014). Interill erosion is largely initiated by soil detachment associated with the impact of raindrops hitting the surface (e.g., Kinnell, 1982; Jayawardena and Rezaur, 2000; Ighodaro et al., 2013). Thus, investigating the influence of rainfall and its subsequent effect on overland flow of water has received considerable attention in recent years in areas where erosion-prone soils are most predominant.

It has been reported that soil detachment from raindrop splash is a direct effect of the kinetic energy from the falling raindrops (Pedersen and Hasholt, 1995; Brodowski, 2013). Rainfall pattern and intensity influence the delivery of kinetic energy from falling raindrops hitting the soil surface (de Lima et al., 2013; Nissan and Tourmi, 2013). As a result,

Submitted for review in August 2015 as manuscript number NRES 11518; approved for publication by the Natural Resources & Environmental Systems Community of ASABE in June 2017.

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rainfall kinetic energy is commonly used in empirical models for soil erosion to predict rainfall-driven soil loss (Rosewell, 1986; Nissan and Tourmi, 2013). It has also been reported that average raindrop size may change depending on climate zones (Yabubu et al., 2014). For example, the average rainfall in tropical zones tends to have a higher proportion of larger raindrops, while average rainfall in temperate zones tends to have smaller drops (Hudson, 1993). Therefore accurate measurements of the size, mass, and velocity of raindrops, which influence the delivery of kinetic energy, are needed by region to more accurately determine the erosive effects rainfall may have on erosion-prone soils.

Investigations into falling raindrop size and influence of raindrops on soil erosion have been ongoing for more than a century. Some of the most widely used methods from early works include the paper staining method described in Hall (1970). This method was pioneered by Weisner (1895) and is based on the assumption that a water drop strikes and soaks into filter paper that has been dusted with dye, leaving behind a stain whose diameter is proportional to the drop's original diameter. The oil bath method described by Gunn and Kinzer (1949) measured the size of small raindrops (2.1 mm diameter or less) under laboratory and field conditions. This method consists of capturing water drops in a shallow dish filled with low viscosity oil (i.e. vacuum pump oil). The flour pellet method developed by Bentley (1904) was used to measure the mass of raindrops as described by Laws and Parsons (1943). The flour pellet method consists of momentarily exposing trays of sifted uncompacted flour to falling raindrops.

Interest in the velocity of falling raindrops also dates back to the early 1900s. Some of the most notable studies evaluating raindrop velocities were conducted by Laws (1941), Gunn and Kinzer (1949), and Wang and Pruppacher (1977), at elevations near sea level (Hinkle et al., 1987). Laws (1941) used high-speed photography (stroboscopic photography) to capture multiple images of falling raindrops on film to determine velocity. Gunn and Kinzer (1949) measured terminal velocity of falling water drops by employing an electromagnetic charge into raindrops as they passed through an energized coil.

In recent years, technology has changed the ways raindrop size, velocity, and distribution are measured. Automated sampling devices have replaced some of the commonly used early methods. Presently, optical disdrometers and rainfall disdrometers are the most commonly used instruments for gathering automated records of drop size distribution. However, these electronic instruments are primarily designed for meteorological studies of cloud physics. Given that these devices are highly sophisticated and relatively expensive, their use for routine studies on soil erosion in poor regions of the world has been impeded (Jayawardena and Rezaur, 2000).

In order to simulate the influence that falling raindrop kinetic energy has on soil erosion, accurate measurements of raindrop size and velocity under field conditions are needed to better represent the mechanics of soil detachment during rainstorm events for modeling and predictive purposes. The objective of this study was to evaluate an inexpensive approach that could be used to measure the kinetic energy of falling raindrops (diameter > 0.4 mm) under natural rainfall conditions in the Loess Plateau region of Northwest China. Herein is described a simplified method for estimating the kinetic energy of raindrops.

Materials and Methods

Raindrop kinetic energy was determined using a relatively inexpensive device designed similar to that of Schmidt (1909) for evaluating transient water drop impact under rainfall at Northwest Agricultural and Forestry University's Soil and Water Conservation and Desertification Control Agricultural Research Station in Yangling District, Shaanxi Province of China. This device essentially consists of two components: absorbent paper for recording raindrop diameter and a pair of rotating disks for determining raindrop velocity. Collecting responses of representative raindrops was achieved by exposing this device to natural rainfall for a relatively short time period. The following section provides a more in-depth description of this device and its use for determining raindrop kinetic energy.

Raindrop Diameter and Calibration

The "paper staining" method was used for determining raindrop diameter. According to Laws and Parsons (1943), the paper staining method is based on the assumption that as a falling raindrop strikes the surface and soaks into an absorbent paper, it leaves behind a stain whose diameter is proportional to the raindrop diameter. Medium-speed filter paper (Whatman No. 1, GE Healthcare Life Sciences, Little Chalfont, Buckinghamshire, UK) was used as the absorbent paper for this study. The filter paper was treated with a 1:10 ratio of eosine and talcum by weight. The water-soluble powder solution (eosine:talcum mixture) was spread evenly onto the filter paper using a brush. This powdered solution doesn't show color when dry, but leaves a permanent rough stain when wetted with a water drop. The resultant stains made on the absorbent paper are rendered permanent by the dying solution. To obtain a mathematical relationship between raindrop size and its corresponding stain diameter left on the filter paper, a calibration curve was constructed using hypodermic needles of different diameters attached to a syringe under laboratory conditions. The inside diameters of the needles used for calibrations were 0.5 mm (type 5), 0.6 mm (type 6), 0.7 mm (type 7), 0.8 mm (type 8), 0.9 mm (type 9), 1.2 mm (type 12) 1.6 mm (type 16), and 2.0 mm (type 20). The size of the water drop produced by the hypodermic needle increased as the needle inside diameter increased. Masses of the water drops were also determined by weighing 100 drops to the nearest 0.1 mg using an electronic balance. For calibrating drop size versus stain diameter, 10 drops from each needle size were dripped onto the coated filter paper. To minimize influence of one stain on another, an effort was made to avoid placing the water drops close to one another. The diameters of the stains on the filter paper were measured using Adobe Photoshop (Adobe Systems, Inc., Mountain View, Calif.) and validated with a compass to determine their average diameters. Characteristics of the water drops for each size of hypodermic needle used are