Geoderma 232–234 (2014) 556–562

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

A method for measuring erosive flow velocity with simulated rill

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ARTICLE INFO

Article history:
Received 17 February 2014
Received in revised form 30 May 2014
Accepted 14 June 2014
Available online 25 June 2014

Keywords:
Sandpaper
Simulated rill
Shallow water flow
Velocity
Pulse Boundary Model

ABSTRACT

The water flow velocity along an eroding rill is of interests for understanding rill erosion hydrodynamics. Soil erosion makes the measurement of flow velocity highly variable. In this paper, a new method is suggested to simulate rills so as to make controllable and efficient measurements of erosive velocity of rill flow. A series of comparative flume experiments were conducted to verify the method by measuring the shallow water flow velocity, along both the simulated and real rills, by using a computerized electrolyte tracer method. The experiments involved three flow rates (12, 24 and 48 L/min) and three slope gradients (5°, 10° and 15°). Five sensors were used to trace the solute transport processes at 30, 60, 90, 120 and 150 cm from the location where the salt solute was injected into the water flow. Flow velocities under simulated rill and real conditions were computed by fitting the measured solute transport processes with its analytic solution. The results showed that under different flow rates and slope gradients, velocities along the simulated rill agreed very well with those along the real rill. This demonstrates that the simulated rill well simulates the real rill. This method will help further study of the hydrodynamics in eroding rill.

1. Introduction

Rill erosion is a serious problem on cultivated slopes of many parts of the world. The hydraulic features of the eroding flow play important roles in rill erosion. Rill erosion occurs under specified circumstances, to involve soil detachment, sediment transport and deposition. It's complicated in mechanism and has long been a focus of concern in developing and improving process-based erosion prediction models.

Water flow velocity is closely related to such soil erosion processes as detachment of soil particles, scouring of soil mass, transport of sediments, and/or deposition of sediments, in such erosion models as WEPP (Nearing et al., 1989), EUROSEM (Morgan et al., 1998) and GUEST (Misra and Rose, 1996; Rose et al., 1983). In these models, movement of water at soil surface supplies energy for soil erosion. Moving water supplies shear stress and/or energy to detach/separate particles from soil surface/body and transport or deposit sediments along the path of water flow. All these processes are closely related to water flow velocity. Rill flow is the motive power to detach soil from the rill surface, as well as the carrier of the sediment. The determination of flow velocity is of great importance for rill erosion. Therefore, the measurement of shallow water flow velocity along an eroding rill is of great interests.

The depth of rill water flow is typically very shallow, usually in mm or cm, and influenced by many factors. The existing measurement methods for flow velocity include tracer method using different materials such as dyes of various colors, salts, heat pulses, radioisotope materials, floating objects (Bresler, 1973; Lei et al., 2010; Luk and Merz, 1992; Zhang et al., 2010), volumetric method, hot film method, Particle Image Velocimetry (PIV) method, photoelectric sensor method and conductance sensor method (Bruun, 1996; Giménez et al., 2004; Hyun et al., 2003; Li et al., 1997; Liu et al., 2007, 2008). Among these different methods, the dye and salt tracer methods are cheap and easy to operate, the others are high in cost or not suitable for the measurement of rill velocity. Some methods such as radioisotope tracer method are not environmentally friendly.

Dye Tracer method is a traditional tracer method. Because its simplicity, easy operation and low cost, it has been widely used. The velocities measured by this method need to be re-calibrated or corrected with different correction factors to get the average velocity, with no universally acceptable and applicable correction coefficients (Dunkerley, 2001; Emmett, 1970; Horton et al., 1934; Myers, 2002; Zhang et al., 2010). It is difficult to obtain empirical calibration parameters since they are related to the flow velocity, diffusion dispersion coefficient, and the sediment content in the flow (Olivier et al., 2005). In addition, the Dye Tracer method needs a relatively long distance for measurement because dye diffusion and visual error may cause high measurement error if the measurement distance is too short.

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http://dx.doi.org/10.1016/j.geoderma.2014.06.014
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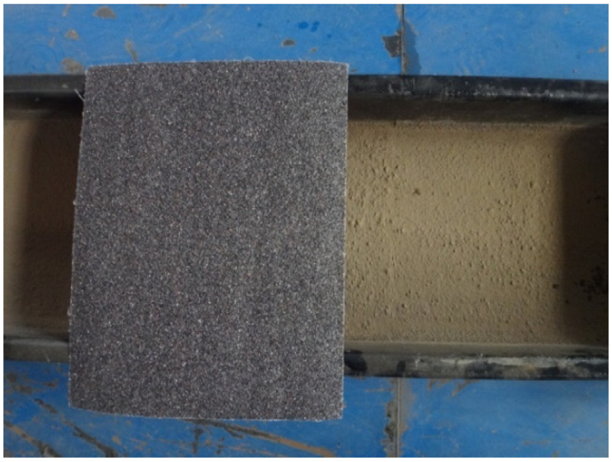

Fig. 1. The sandpaper before and after being glued with soil particles.

An electrolyte tracer method for measuring shallow water flow velocity, based on mathematical solution of solute transport in water flow under pulse boundary condition was suggested by Lei et al. (2005). The method uses the analytical solution to the partial differential equation for solute transport in the shallow water flow, under the assumed pulse boundary condition. By fitting the experimentally obtained solute transport process data with the solution to the partial differential equation with the Least Square Method, the shallow water flow velocity is determined. This method needs no calibration.

Rill erosion processes such as detachment, transport, and deposition depend mainly on the hydraulic features of water flow in the rills. Unlike the flow hydraulics in concrete channels, a rill is usually very variable in cross section spatially and temporally, which make measurement of velocity, depth, shear stress, and other hydraulic parameters highly variable (Foster et al., 1984).

Shallow water flow velocity depends on such factors as slope gradients, slope length, flow rates, and roughness of underlying surface. Consequently, it is a key and hard issue to propose an accurate and easy way to measure shallow water flow velocity. In the laboratory measurement, the rills need to be reformed, so as to keep the measurement more or less uniform from one experiment to another. Therefore, new method for simulating rill flow hydraulics is in need. Sand paper or gluing sand or sediment particles on flume was used to simulate soil surface for study of rill velocity (Dunkerley, 2001; Lei et al., 2005; Zhang et al., 2010). In this method, sand papers or soil and/or sand particles are glued onto the flume surface to simulate the grain roughness of naturally eroding surface. However, the particles on sand paper are different from soil particles in size and hardness. Moreover, little information of the difference between the simulated surface made of sand paper or glued soil particles, and the real soil surface was provided.

In this study, a new method is suggested to simulate rill surface, and the velocities of water flow over the simulated surface and those over a real rill (soil-formed rill) were measured by the electrolyte pulse method. A series of experiments were conducted to: 1) define the procedures to simulate rill by sand paper glued with soil particles; 2) clarify the effect of the distance between the source and the measuring section along the flume; 3) estimate the relative error of the velocity along the simulated rill and real rill under different hydrodynamic conditions.

2. Methods and materials

2.1. The experimental facilities and method

The experimental system was set up with the following components: a water supply tank, a flume, and a flow velocity measurement system. The water supply tank is a Mariotte bottle made of plexiglass, 0.236 m^3 in capacity, used to supply water flow of the controlled and constant flow rate to the flume. The flume of 3.8 m long, 20 cm wide, and 8 cm high, made of steel was used to simulate the rill, by which the solute is transported in the water flow. A box of 20 cm long, 20 cm wide, and 8 cm high was set at the upper end of the flume to stabilize the water flow and to distribute the water flow evenly in the flume cross section. A shutter was located at the lower end of the flume to maintain the water level and to drain the flow.

2.1.1. The real rill preparation

A silty loam, composed of 11.98% clay (<0.002 mm), 81.17% silt (0.002 to 0.05 mm), and 6.85% sand (0.05 to 2 mm), taken from Koxkar Glacier basin in Akesu, the Xinjiang Uygur Autonomous Region, was used to form the rill. The soil was air-dried and passed through a 10-mm sieve prior to eliminate grass roots and stones. The experimental soil was then packed evenly into the flume at uniform depth layers of about 5 cm depth at a bulk density of 1.0 g/cm^3. The packed rill soil was saturated from above with tap water and allowed to set for a day (24 h) prior to each experimental run in order to facilitate consistent pre-wetted condition and to eliminate any effects of uneven packing.

2.1.2. The simulated rill preparation

Sand papers with an average granular diameter of 0.764 mm (Grit size of 24) were glued onto the bottom of the flume before soil particles were glued onto the sand paper. After compaction with heavy bricks for 12–24 h, the soil particles which were not stuck onto the sand paper were cleaned up. The simulated rill was showed in Fig. 1.

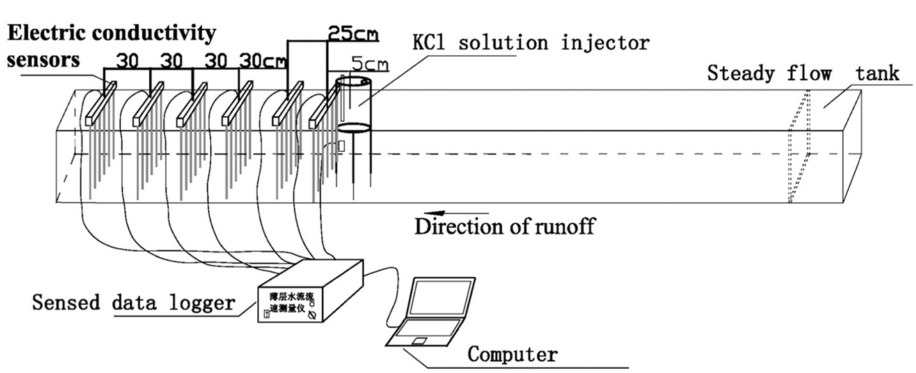

Fig. 2. The sketch of experimental equipment system.