Discussion


P.I.A. Kinnell*

University of Canberra, School of Resource, Environmental and Heritage Sciences, Canberra, ACT 2601, Australia

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Abstract

Gao et al. [J. Hydrol. 277 (2003) 166] analyzed the results of a simple experiment to test the theoretical relationships for two factors in a mechanistic model. They concluded that the theoretical values for the parameter $a$, the parameter that accounts for the effect of water depth on the amount of material detached and lifted into the water by raindrop impact, and the exponent of rainfall intensity were appropriate. Previous work on the mechanics of erosion by rain-impacted flow supports the concept that there is a direct relationship between rainfall intensity and sediment discharge by rain-impacted flow, as do the experiments of Gao et al. Fundamentally, an exponent value of one indicates that variations in the time period between successive drop impacts do not significantly affect the ability of a drop impact to detach and transport soil material in rain-impacted flows. However, theoretically, the form of the relationship between the amount of material in the water layer and water depth observed by Gao et al. may be produced by a $a$ to water depth relationship that differs from the one used in the mechanistic model. Some of the response relationships in the mechanistic model are based on experiments that were not designed to determine the nature of those particular relationships. Because of this, these relationships are conceptual and have not properly verified by experiment. Gao et al. strived to overcome this deficiency using a simple experiment. This work is a step in the right direction and is to be encouraged.

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While Gao et al. (2003) present results from a simple experiment in the context of a mechanistic model, consideration of these results in the light of previous work on the mechanics of raindrops impacting water over erodible surfaces is worthwhile.

The mechanistic model (Rose and Dalal, 1988, Harisine and Rose 1991, Rose et al., 1994; 1998) that spawns the experiments was originally developed while some of the work on the effect of interaction between raindrop impact and flowing water on the erosion of loose material was in its early stages, and the exponent $p$ in Eq. (3) was taken as 2 after consideration of work presented in the literature. Of note was the work of Meyer (1981) which suggested that interrill erosion was related to intensity squared. Subsequent analysis of Meyer’s data by Kinnell (1993a) indicated that sediment concentrations in
Meyer’s experiments were directly related to rainfall intensity so that the intensity squared model reflected the fact that sediment discharge was the product of runoff rate and sediment concentration when both varied directly with rainfall intensity. This result was consistent with laboratory experiments with rain-impacted flow over sand when flow depth, flow velocity and rainfall intensity were varied in a series of controlled laboratory experiments (Kinnell, 1991). Kinnell (1993b) went on to show that the product of runoff rate and intensity provided a good basis for modeling interrill erosion and the product was later adopted in WEPP (Flanagan and Nearing 1995). Thus there is pre-existing evidence in the literature to support the concept that \( p = 1 \) when raindrop size does not vary significantly with rainfall intensity. Fundamentally, \( p = 1 \) indicates that variations in the time period between successive drop impacts do not significantly affect the ability of a drop impact to detach and transport soil material in rain-impacted flows.

Given that variations in the time period between successive drop impacts do not significantly affect the ability of a drop impact to detach and transport soil material in rain-impacted flows, as pointed out by Gao et al. the relationship between the amount of material in the water above their soil surface and ponding depth should be independent of rainfall intensity. Each drop contributes about 0.05 ml of water to the ponded volume and consequently the number of drops and pond depth are directly correlated to each other. Given a cross sectional area of 45 cm², each drop impact increases the depth of the water layer by about 0.011 mm. Consequently, if the settling velocity equals zero, the mass of sediment in the water layer at any depth \( D \) will depend on the number of drops that have contributed to the volume of the water layer \( (\approx D/0.011 \text{ for } D \text{ in mm}) \) and the mass material lifted by each drop impact \( (M_d) \) since the first drop. Thus, if the mass of material lifted by a drop impact remains constant as \( D \) increases, then the \( M-D \) relationship will be linear and flatten if a depth is reached when the drop impact can no longer disturb the soil surface. It will show some deviation from this response if \( M_d \) varies with \( D \) as one would expect in reality.

The mechanistic model contains a factor \( a \) that is, in theory, constant until some depth \( (D_a) \) is exceeded. Once \( D \) exceeds \( D_a \), \( a \), in theory, decreases exponentially with ponding depth. In the context of the Gao et al. experiments, \( a \) is directly related to \( M_d \), the mass of material lifted into the water layer by a drop impact, and \( M_d \) depends on how the energy of the drop is utilised. Normally, detachability is a term used to reflect the ease by which a soil surface erodes because of the inherent nature of the soil. In this respect, \( a \) is incorrectly described as an index of detachability. Not withstanding this, because of its relationship to \( M_d \) in the Gao et al. experiments, its use in the analysis leading to Fig. 7 needs to be considered in relation to previous work on the mechanics of drops impacting water layers.

According to Harisine (pers comm), the theoretical response of \( a \) to \( D \) was derived from an analysis by Kinnell (1991) of data obtained by Moss and Green, 1983. However, the variable considered by Kinnell was the product of the average mass of material lifted by a drop impact at a given flow depth and the time the mass remained suspended in relation to transport of material across a boundary. Kinnell considered experiments where the eroding material had significant settling velocities, and the time that the material was suspended was restricted by the height of the water surface above the eroding surface when flows were very shallow. If the product considered by Kinnell remains constant as flow depth decreases then there must be an increase in \( M_d \) as flow depth decreases to compensate for the reduction in the time the particles are suspended. Kinnell was working with data from a system where some of the material lifted by a drop impact was deposited before it could cross the downstream boundary. That amount increased as flow depth decreased when flows were shallow. This situation is quite different from that in the Gao et al. experiments where settling velocities were zero, or close to zero, and there was no sediment discharge. Also, apart from the difficult in sampling the water layer mentioned by Gao et al. in very shallow rain-impacted flows, soil material is lost from the water layer by splash transport and the apparatus used by Gao et al. did not allow that to happen. In addition, the analysis of the \( M \) to \( D \) relationship though Eq. (6) and Fig. 7 does not necessarily confirm the theoretical relationship for \( a \) to \( D \). As indicated by Fig. 1 here, other forms of \( a \) to \( D \) relationship may produce...
a similar form of $M$ to $D$ relationship to that obtained by Gao et al.

There is no doubt that $M_d$ decreases with flow depth over some range of flow depth. The $M$ to $D$ relationship observed by Gao et al. would not exist unless this were so. The primary reason for the decline is that flow depth influences how the energy of a drop impact is used to lift soil material from the surface up into the water layer. Observations on what happens when a drop impacts a water layer have been reported by a number of workers. A medium (2.5 mm) to large (6 mm) sized raindrop traveling at or near terminal velocity produces a cavity about three drop diameters in depth. If the water layer is shallow enough for the cavity to reach the soil surface, the soil surface is subjected to high velocity flows that occur along the edges of the cavity. When sediment is discharged by rain-impacted flow, there is a non-linear decline in sediment concentration with flow depth when the flow is shallow enough for the cavity to reach the eroding surface (Kinnell, 1993c). However, detachment still occurs when the flow is deeper than three drop diameters. In this case, detachment is caused by the collapse of the Raleigh Jet and the fall of an associated large droplet which form when the cavity collapses. The form of the sediment discharge to flow depth remains non-linear when $D$ is greater than 3 drop diameters but the decline with an increment of depth is much greater than when $D$ is less than three drop diameters. A similar non-linear ‘broken stick’ type of relationship may occur with $M_d$. If so, $D_0$ may reflect the change in the mechanism that produces the detachment and uplift of the soil material. Dropping single drops from 3 m into water layers of various depth and observing the drop-water layer interactions would provide some insight into this.

As indicated above, some of the response relationships in the mechanistic model are based on experiments that were not designed to determine the nature of those particular relationships. Because of this, these relationships are conceptual and have not properly verified by experiment. The work of Heilig et al. (2001) and Gao et al. (2003) strive to overcome this deficiency using simple experiments. This type of work is a step in the right direction and is to be encouraged.

**References**


