INTERACTION BETWEEN FLOW-DRIVEN AND RAINFALL-DRIVEN SOIL EROSION PROCESSES USING TWO CONTRASTING SOIL TYPES

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Abstract
The effect of interaction between erosion processes has not been studied in detail, so that the existing available literature, which directly addresses the interaction between erosion processes, is very limited. Numerous laboratory experiments have shown that the rate of erosion in a rain-impacted flow is greater than for unimpacted flows of similar depth and velocity. In erosion studies and in modeling the processes involved it is questionable whether it is justifiable to simply add the contribution of each separate erosion processes to give the total sediment concentration, or whether there may be some form of interaction between the two types of erosion process, positive or negative. Current modeling methods only indirectly have implication for the magnitude of such interaction. The experiments reported in this paper were carried out in the 5.8 by 1.0 m Griffith University Tilting Flume Simulated Rainfall (GUTSR) facility, using two different soil types. It was found that sediment concentration due to flow-driven and rainfall-driven erosion processes, or combination of both processes, depends on soil type and slope steepness. It was found that at low slopes rain-impacted flow can erode soil more rapidly than comparable flow without raindrop impact. At steady state or apparent equilibrium conditions there was a positive or synergistic interaction between rainfall and flow-driven erosion for the silty soil with a finer soil size characteristic than the coarser loamy sand, where the interaction was negative.

Additional Keywords: silty soil, loamy sand, processes-based models, GUEST model

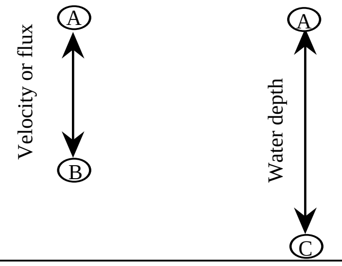
Introduction
There is general agreement among researchers that sediment loss due to flow-driven processes can be increased by rainfall-driven processes and vice versa (eg. Singer *et al.*, 1981; Dillaha and Beasley, 1983). Proffitt and Rose (1991a) showed the relative importance of rainfall-driven and flow-driven erosion processes, formerly investigated in some extent by Quansah (1985) and Guy *et al.* (1987a). In erosion studies and in modelling the processes involved it is questionable whether it is justifiable to simply add the contribution of each separate erosion processes to give the total sediment concentration, or whether there may be some form of interaction between the two types of erosion process, positive or negative, which may also be significant. Current modelling methods only indirectly have implication for the magnitude of such interaction. For example in the WEPP program (Lane and Nearing, 1989; Nearing *et al.* 1989), if the computed sediment concentration exceeds the transport limit, then the computed concentration is adjusted to the transport limit value. A similar comment of this also applies to GUEST (Misra and Rose, 1989). The interaction between rainfall and flow-driven processes is both more important and best quantified in the absence of significant rills. Thus interaction experiments were restricted to a range of modest slopes in which the soil investigated did not develop rills. Thus the results of this study are intended to enhance understanding of the interaction between rainfall-driven and flow-driven erosion processes in a quantitative manner that can be used in process-based models.

Materials and Methods
In order to derive the quantitative interaction between erosion by rainfall impact and overland flow a combination of experiments was conducted with rainfall alone, runon alone, and rainfall and runon acting together. Thus three different experiments were carried out on each of two soil types, the types of experiment being classified as series A, B and C respectively. Details of the series A, B and C experiments are given in Table 1.

The conditions in all experiments were chosen so that rills did not develop, so that the flow was in sheet form.
In order to set up experiments with the same velocity or the same flux with and without rainfall, the effect of rainfall impact on slowing down flow velocity also needs to be understood. For any given flux, the depth of flow depends on the effective roughness as indicated by the inter-related hydraulic roughness parameters such as Mannings n, Chezy's C or the Darcy-Wiesbach friction factor f. Roughness itself varies with soil and flow conditions, as investigated in Rouhipour *et al.* (1999), where a unique relationship between Manning's n and velocity of flow was established for any particular soil. This relationship was used in the design of series A and B experiments where velocity of flow was required to be kept the same (Table 1).

Table 1. Chart summarising design and type of experiments.

Experiment series	Description	Factor kept same
A	Rainfall+runon	
B	Runon alone	
C	Rainfall alone	



Soils investigated

Two types of soil with different characteristics were used throughout this study. Soil No 1 was a loamy sand from a pineapple farm at Goomboorian near Gympie, (South East Queensland) classified as an Albic Arenosol in FAO system of soil classification. It is hereafter referred to as loamy sand or Goomboorian soil. Soil No 2 was a silty loam from Redlands Horticultural Research Station in Ormiston, Brisbane), with a classified as soloth in the Australian system and Naorudalf in the US taxonomy (Powell, 1982). Soil characteristics are given in Table 2.

Table 2. Some physio-chemical characteristics of the two soils, Goomboorian loamy sand and silty loam used in the experiment .

Soil type	**Depth (m)**	**pH** (1) **(1:5)**	**EC dS m^{-1}**	**OM**(2) **%**	**C-sand**(3) **%**	**F-sand** (4) **%**	**Silt %**	**Clay %**
Loamy sand	0.0-0.20	5.1	0.134	1.2	33	52	6	9
Silty loam	0.0-0.20	5.6	0.03	2.00	16	48	25	11

(1) aqueous 1: 5, soil:water; (2) OM= organic matter; (3) C=coarse; (4) F=fine

Theory for series A and B experiments

In order for the flow-driven contributions to sediment concentration to be comparable for series A and B experiments, it is required to provide the same flux or flow velocity at the flume exit for both experiments. The same flux requires that: $q_a(L) = q_b(L)$, where q_a and q_b is the volumetric flux per unit width in series A and B experiments respectively measured at flume exit and L denotes the length of soil bed in the flume of slope S. $q_b(L)$ is the volumetric flux due to runon only in experiment series B, applied at the top of the soil bed but constant over the entire soil bed. A particular value of $q_b(L)$ was selected. Since, $q_a(L) = q_{in} + QL$, this q_{in} in experiment A can be directly calculated from:

$$q_{in} = q_b(L) - QL \qquad (1)$$

where, q_{in} is the volumetric flux per unit width added as inflow to the top of the flume in series A experiments, Q is the runoff rate per unit area. Since the soil bed in the flume with impermeable base was saturated prior to each experiment, Q is equal to rainfall rate.

The second series of experiments require that the velocity of flow at exit from the flume is the same for both A and B experiments. This was achieved as follows. Using the same flux $q_a(L)$, but with inflow q_{in} and rainfall, the average velocity in series A experiments $\overline{V}_a$, was measured using the salt tracing technique((Luk and Merz, 1992; Li, *et al.* 1996; Rouhipour, *et al.* 1999). The value of Manning's n denoted n_a in series A experiments, was then calculated using modified Manning's equation developed by Rouhipour *et al.* (1999) for rain-impacted flow. In experiment B it is desired to find $q_b(L)$ such that $\overline{V}_b = \overline{V}_a$, we require that $n_b = n_a$ then from Manning's equation:

$$q_b = \frac{n_a^{3/2}\overline{V}_a^{5/2}}{S_b^{3/4}}, \qquad (2)$$

where S_b, stands for flume inclination in series B experiments. Thus equation (2) allows the calculation of q_b. (It was later checked experimentally that $\overline{V}_b = \overline{V}_a$).

Theory for series A and C experiments
For these series of experiments, water depth is needed to be the same at flume exit, (table 1), and assuming that Manning's n to be the same for both experiments $n_a = n_c$, gives:

$$q_c(L) = QL = D_c V_c = \frac{S_c^{1/2} D_c^{5/3}}{n_c} \text{, and also} \quad (3)$$

$$q_a(L) = q_{in} + QL = D_a V_a = \frac{S_a^{1/2} D_a^{5/3}}{n_a} \quad (4)$$

Dividing both sides of equation (3) by (4) and considering $n_a = n_c$ gives:

$$\frac{S_a}{S_c} = \left(1 + \frac{q_{in}}{QL}\right)^2 . \quad (5)$$

Equation (5) was used to provide slopes for soil bed in series C experiments (S_C), with all other terms in the equation given for series A experiments. In summary the interaction expressed in terms of sediment concentration is given by:

$$Interaction = c_a - (c_b + c_c), \quad (6)$$

where c_a, c_b *and* c_c are the sediment concentration in series A, B and C experiments respectively. The calculation of interaction is based on sediment concentration at or close to equilibrium. Equilibrium conditions, or effective equilibrium conditions, were assumed to have been reached when sediment concentration remained approximately constant with time.

Results and Discussion
The relative percentage contribution to total sediment concentration (taking the contribution from series A experiment as 100%) of rainfall alone, runon alone, and interaction between erosion processes due to both causes when acting together are plotted against streampower) and mean flow velocity (Figure 1) for silty loam soil and (Fig. 2) for loamy sand soil or Goomborian. In these figures, the sediment concentration due to the combined effects of rainfall and runon are shown by curve (A) as 100 %. The percentage contribution by runon alone to this total sediment concentration is shown by curve (B), due to rainfall alone by curve (C), and the outcome of interaction (equation 6) by curve (D).

Silty loam soil
As streampower increases, Fig. 1 show that the percentage contribution of flow-driven erosion (curve B) increases, while as expected, the contribution of rainfall-driven erosion (curve C) generally decreases. Thus at low streampower, rainfall-driven erosion dominates, and as streampower or flow velocity increases, the role of rainfall becomes less pronounced and that of overland flow becomes increasingly important. This is in agreement with the theory and general experience reported in the literature (Yoon and Wenzel, 1971; Shen and Li, 1973).

The data shown in these figures indicates that the sum of sediment concentration due to rainfall and runon occurring separately, are less than the sediment concentration achieved by these processes acting together, indicating a positive interaction at the low slopes (1% to 3.4%) typical of these experiments with silty loam in sheet form.

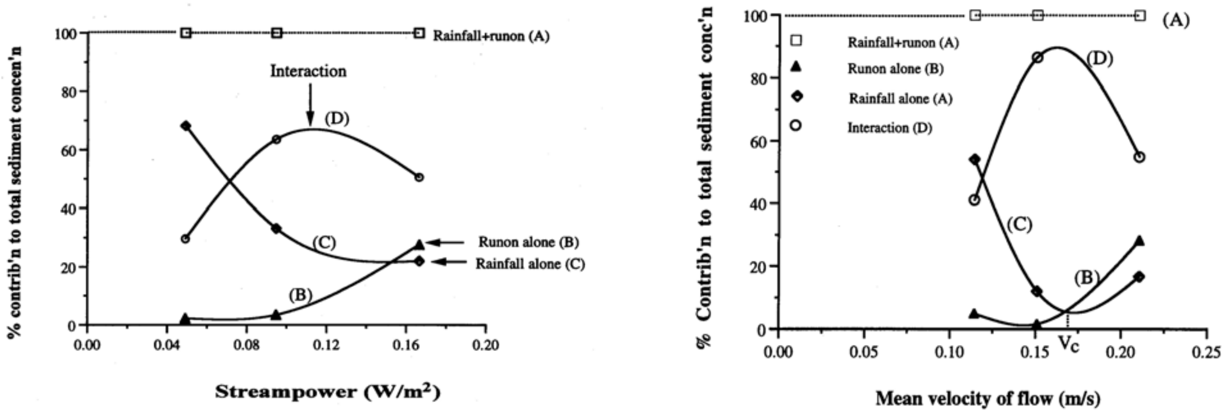


Figure 1. Percentage contribution at equilibrium by flow-driven (curve B) and rainfall-driven (curve C) to sediment concentration from the combined interaction of rainfall plus runon shown as 100% (A), with flux constant for A and B experiments (right) and velocity constant (left). Percentage interaction also shown (D). Three slopes used in these experiments were 1%, 1.5%, and 3.4%. Rainfall rate was 100 mm h^{-1}. Soil type is a silty loam.

Loamy sand soil

Over the whole ranges of streampower or flow velocity investigated, curve D in Figure 2 show interaction to be negative, indicating that sediment loss due to the combined effect of rainfall plus runon is less than sum of sediment loss due to rainfall and runon occurring separately. Thus the effect of rainfall on flow for this type of soil is antagonistic and not synergistic to sediment loss when both erosion processes are acting. Reasons for the differences in interaction for the two soil types investigated will be discussed in what follow.

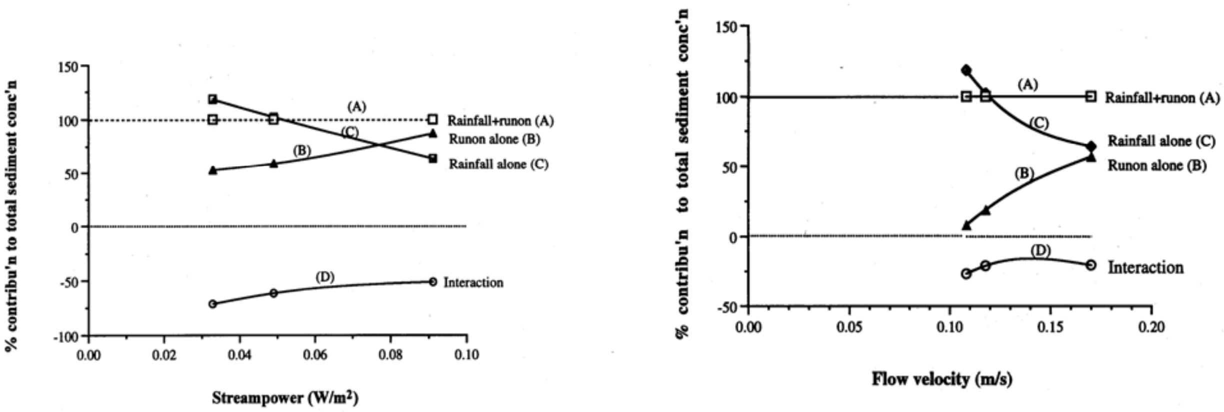


Fig. 2 Percentage contribution at equilibrium by flow-driven (B) and rainfall-driven (C) to sediment concentration from the combined interaction of rainfall plus runon shown as 100% (A) with velocity constant(left) and flux constant (right) for A and B experiments. Percentage interaction also shown (D). Three slopes used in these experiments were 0.5%, 1%, and 1.5%. Rainfall rate was 100 mm/h. Soil type is a loamy sand or Goomboorian soil.

Discussion

The difference in sign of the interaction at equilibrium between rainfall and flow-driven erosion for the two quite different soil types investigated calls for explanation. In considering possible reasons for the difference in interactive behaviour exhibited by the two soils the following characteristics of flow under rainfall and of soil bed characteristics may well be of significance. The silt loam soil possessed significantly greater strength and lower depositability than the loamy sand (Rouhipour, 1997). The strength of the silt loam restricted sediment concentrations under runon alone, and the much higher shear stresses under rainfall impact greatly enhanced sediment concentrations. The low depositability of the silt loam helped maintain high sediment concentration. Runon in the presence of rainfall led to sediment concentrations considerably greater than rainfall alone, as though rainfall impact significantly weakened the soil surface so that flow shear stresses would be effective in soil removal. This was apparently reason for the positive interaction between rainfall + runon demonstrated by this soil (Figure 1).

Characteristics of the loamy sand were a lower strength and higher depositability than the silt loam. The higher depositability was apparently the reason for the generally lower sediment concentrations measured for the loamy sand compared to the silt loam. However maximum streampowers and velocities were lower for loamy sand experiments. It could well be the relative weakness of the loamy sand which allowed the lower sediment concentrations to be somewhat similar whether due to runon alone, rainfall alone, or a combination of both eroding agents. It is suggested that the negative nature of the interaction found for loamy sand is that rainfall suppressed the formation of protorills or microrills present with runon alone. Thus the expected increase in sediment concentration from the addition of rainfall may have been largely negated by microrill suppression, so reducing the effectiveness of runon in erosion (Figure 2).

Conclusions

It was found that sediment concentration due to flow-driven and rainfall-driven erosion processes, or combination of both processes, depend on soil type and slope steepness. For flow alone, and both erosion processes acting together, sediment concentration increases with flow velocity or streampower, and thus with water flux and slope gradient. This study illustrated the relative importance of raindrop impact or overland flow for soil erosion. It was found that at low slopes rain-impacted flow can erode soil more rapidly than comparable flow without raindrop impact. The degree of enhancement was also found to be dependent on the soil type and other flow parameters such as flow depth and velocity or stream power. At steady state or apparent equilibrium conditions there was a positive or synergistic interaction between rainfall and flow-driven erosion for the silty soil with a finer soil size characteristic than the coarser loamy sand, where the interaction was negative.

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