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Interaction between Rain and Runoff Processes during Rainstorm Erosion Events

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Introduction

Many erosion studies of the past (e.g. 1, 6) have made references to interaction between various erosion processes including interaction between rain and surface flow, but in none of the physically based soil erosion prediction models, interaction between rainfall and flow driven processes is directly represented. More recently Rouhipour et al. (2005) reported the results of their extensive study of interaction between rainfall-driven and flow-driven erosion processes for two contrasting soil types. Contrary to most previous studies, they observed a negative interaction for one soil and a positive one on the other soil. They also showed that interaction between these two processes changes with flow streampower.

The fundamental mechanisms of interaction between rain and surface flow and the reasons for contradictions reported by various investigators and in particular Rouhipour et al. (2005) are still not fully understood. The objectives of this study were (i) to directly investigate the interaction phenomenon on a number of contrasting soils, and (ii) to propose a possible mechanisms and theoretical explanation for such interaction.

Materials and Methods

In order to assess the interaction between erosion by rainfall and flow quantitatively, three sets of experiments were conducted on three soil types using the Griffith University Tilting Flume Simulated Rainfall facility. In the first and 2nd sets (type R and F) the two processes were acting alone and in the 3rd set (type RF) rainfall-driven and flow-driven processes were acting together. The conditions in all experiments were chosen so that rills would not develop (i.e. the flow remained in sheet form). Table 1 summarized the details of the experiments.

Table 1. Type and details of the experiments

Soil Type	Type of experiment	Slope	P	Soil length	q_{in}	q_{ex}	D	Stream power
		(%)	(mm h^{-1})	(m)	(m^3 m^{-1} s^{-1}	10^{-3})	(m 10^{-3})	(W m^{-2})
Black Earth	Rainfall alone (R)	0.1	97	1.42	0	0.038	4.5	0.0004
	Flow alone (F)	2.5	0	5.7	0.200	0.200	4.5	0.0491
	Rainfall + Flow (RF)	2.5	102	5.7	0.039	0.200	4.5	0.0491
Red Earth	Rainfall alone (R)	0.1	110	1.72	0	0.053	4.5	0.0005
	Flow alone (F)	2.5	0	5.7	0.240	0.240	4.5	0.0588
	Rainfall + Flow (RF)	2.5	100	5.7	0.081	0.239	4.5	0.0586
Toohey Soil	Rainfall alone R)	0.1	129	1.72	0	0.061	3.5	0.0006
	Flow alone (F)	2.5	0	5.7	0.246	0.246	3.5	0.0603
	Rainfall + Flow (RF)	2.5	124	5.7	0.070	0.254	3.5	0.0623

P= rainfall rate; q_{in}=additional input of clear water of volumetric flux per unit width of plane,
q_{ex}= volumetric flux of water per unit width of plane at the flume exit, D=water depth at the flume exit.

In this study the flow-driven contributions to sediment concentration was made comparable for type RF and F experiments by making the volumetric flux at the flume exit equal for both experiments. For type R and RF experiments, water depth was kept the same at flume exit. Theoretical formulations were developed for calculating of q_{in} of experiments type RF and soil length of experiments type R (table 1). The yielded streampowers in type R experiments were lower than the threshold value to ensure the absence of flow-driven processes. Interaction in terms of sediment concentration was defined as: $Interaction = c_{RF} - (c_R + c_F)$, where c_R, c_F *and* c_{RF} are the sediment concentration in types R, F and RF experiments respectively.

The Black Earth and Red Earth are both classified as clay texture but the Black Earth has a larger clay fraction (0.64) than the Red Earth (0.43). The Toohey Soil is of much ‘lighter’ texture (sandy) with only 2% clay and 95% sand content. Secondary particle size distributions (aggregates) of the soils were measured by wet sieving. Data on aggregate size distribution was used for subdividing the original soil into *I* size classes of equal mass (*I* was 10 for Black and Red Earth and 20 for Toohey soil). The fraction of each of *I* size classes in outflow sediment at different interval times was also obtained using similar size boundaries obtained from subdividing the original soil into equal classes.

Results and Discussion

1-Erosion processes and transport mechanisms

Fig. 1 gives the sediment concentration for each size class measures at the steady state conditions. For rainfall alone (type R) experiments there is a greater predominance of larger particles (0.5 – 1.5 mm), as against the finer range (0.13 – 0.5 mm), and, except for the Toohey soil, an enrichment of the finest measured fraction. The enriched finer fraction could be arises from the stripping of fine material from stable larger aggregates by raindrop impact as proposed by Ghadiri and Rose (1991). Toohey soil is a sandy soil without any aggregate to be stripped. However all three soils exhibit the apparently preferential transport of a range of larger size classes (Fig. 1) which is not readily explained in terms of structural breakdown, nor by the theory of Hairsine and Rose (1991). Recognizing soil displacement by the high shear stresses at drop impact (3), it is possible that despite the slight slope involved in these experiments (0.1%) there could be a preferential net downslope by some mechanism. Such an interpretation has been suggested by other researchers (e.g. 7) and referred to “splash creep” or “creeping” but without elaborating on its role in the erosion process.

Concerning the erosion of soil by flow alone there is a qualitative difference in size class behavior between the two well-structured soils (Black and Red Earth) and the weakly structured Toohey soil. For the well structured soils only fine material is transported, whereas the concentration is more uniform over the different size classes for Toohey soil. One possible explanation of this difference in type F experiments could be that a larger threshold steampower is required to erode the larger aggregates of the two well-structured higher clay content soils, possibly due to higher cohesion.

Finally, it is the results of type RF experiments which yield the most uneven distribution in sediment concentration by size class (Fig. 1). For the Black and Red Earths the strongly enhanced fine sediment described to raindrop stripping is noticeably lacking in results for the Toohey soil. However for all three soils the distribution of sediment concentration over size classes is much more uneven with rain and runon acting together than is the case when they act separately. Thus, in general, there is evidence of a substantial interaction between the two different erosion mechanisms. The bimodal appearance of sediment concentration distribution plots for all three soils (Fig 1) may be an indication of two transport mechanisms operation simultaneously i.e. transportation of fine particles by suspension and transport of large particles by rolling.

2-Interaction

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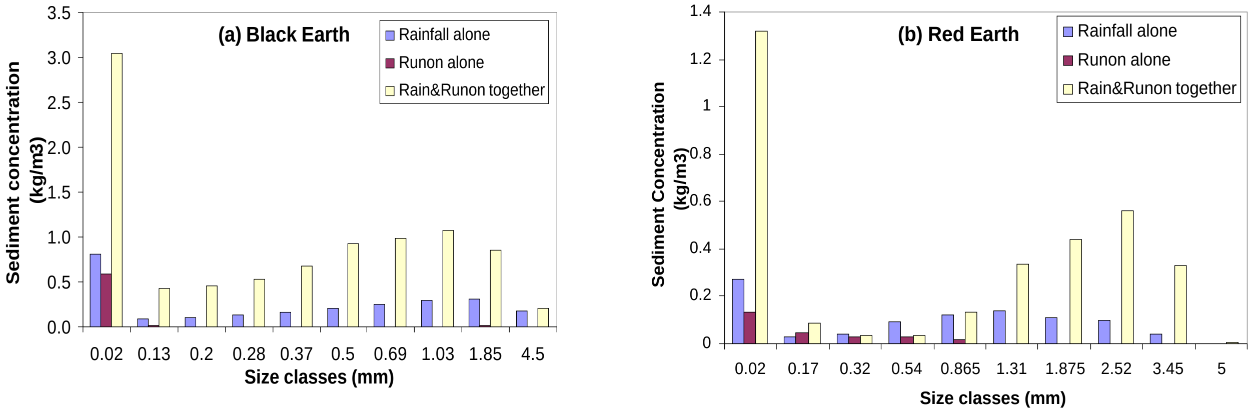
At the steady state condition, interaction was clearly positive with sediment concentration for rain and runoff acting together being about 3, 3, and 2 times that of the two processes acting individually for Black Earth, Red Earth and Toohey soil respectively. Interaction values in terms of sediment concentration were 6, 2, and 5.7 kg m^{-3} for the above three soils respectively. Contribution percentage of each of *I* size classes in increasing sediment concentration due to interaction are presented in Figure 2 for steady state conditions.

Black Earth. The increase is across the size ranges for this soil with one peak for the finest class of <0.019 mm and another one for the coarser class range of 0.5-1.03 mm. The increase in the concentration of fine particles in the eroded sediment may be a result of aggregate peeling by raindrop impact as discussed before. Significant increase in the concentration of other size fractions is clearly the result of positive interaction between these two processes. The significant contribution to this positive interaction of coarser classes of particles could indicate the presence or the enhancement of bed load transport through creeping and rolling mechanisms in rain-impacted flows.



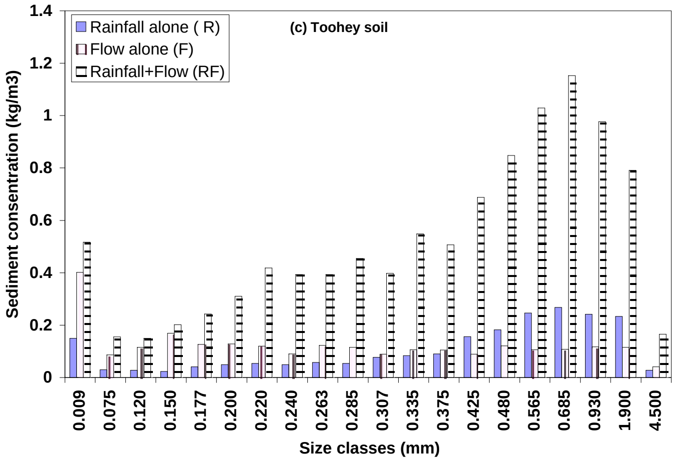
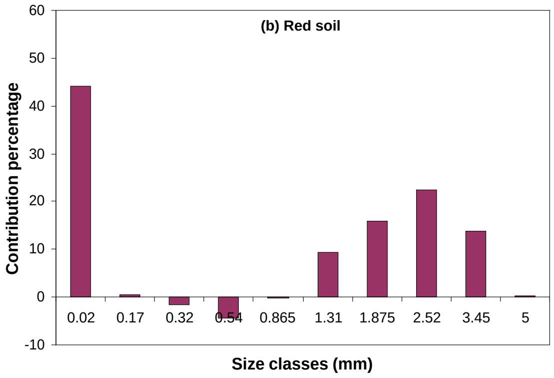
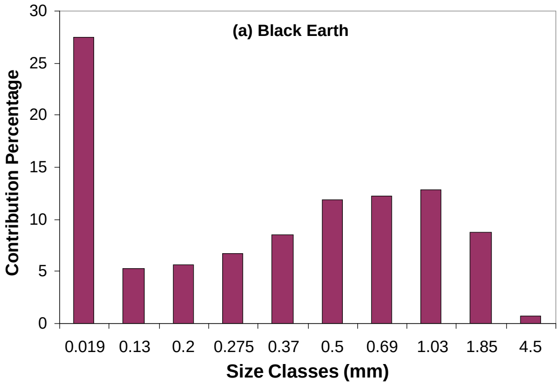


Figure 1- Sediment concentration of individual size classes at the steady state condition for the three types of experiment carried out on (a) Black Earth, (b) Red Earth and (c) Toohey soil

Red Earth. As for Balck Earth the overall interaction effect is positive and the distribution of percentage contribution of individual size classes in increased sediment concentration is bimodal with one peak in the finest size class and the other in the relatively coarse classes (1.87-3.45 mm). This kind of distribution once again supports the proposed breakdown or peeling of larger aggregates by raindrop impact and the enhancement of bed load transport (creeping and rolling) of coarser particles as discussed above. However in contrast to the Black Earth there is zero ornegative interaction for some size classes. This different behavior is probably due to different soil properties. The Red Earth had larger and more stable aggregates than the Black Earth which could have influenced peeling rate and the size distribution of peeled materials.

Toohey Soil. Although interaction on this soil was positive as for the other two soils, particle size distribution and the contribution of each size class to the interaction-induced sediment concentration increase is noticeably different. For Toohey Soil there is no sign of the bimodal distribution of size classes observed for Black Earth and Red Earth. The distribution in Fig 2c shows a gradual increase up to the size class of 0.685 mm. There is no sign of a peak for the finest size class, since this soil has no aggregate to produce such fine particles through peeling mechanism.





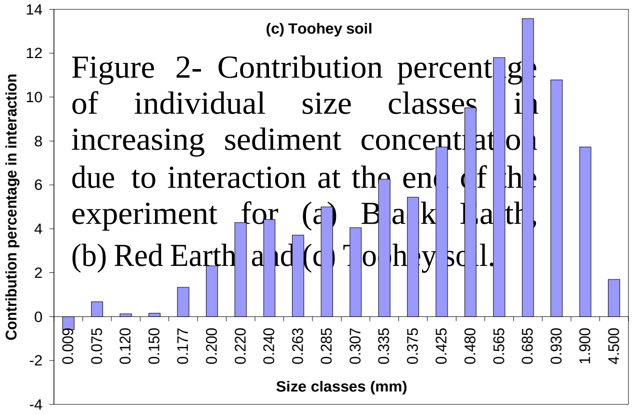


Figure 2- Contribution percentage of individual size classes in increasing sediment concentration due to interaction at the end of the experiment for (a) Black Earth, (b) Red Earth and (c) Toohey soil.

Conclusion

Interaction is generally positive under approximately steady state condition and there is very limited sign of negative interaction reported by others. Results provide strong evidence that raindrops continuously peel fine sediment from larger stable aggregates, a mechanism which has been previously identified. This mechanism received strong positive interaction during simultaneous rainfall and flow driven erosion. Strong positive interaction between these two forms of erosion also occurs for medium to large aggregates. This strongly suggests that mechanisms which are not well understood are operational. It is quite possible that particle movement can be stimulated by rolling or creeping in a size-selective manner. Indeed, such additional mechanisms may well be largely responsible for the positive interaction observed between rain and surface flow. Evidence of such strong interaction between rainfall, and flow-driven erosion, and the possible indication of a wider range of mechanisms than normally considered presents a new challenge to erosion modeling.

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