The Effect of Raindrop Impact and Slope Length on Sediment Concentration of Runoff

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Introduction

The importance of raindrop impact on soil detachment has been recognized for many years (1, 2, 8). The importance of slope length and its influence on the total erosion process has also been recognized for some time (8). There is no question that high sediment concentration in runoff is associated with excessive erosion that leads to reduced soil productivity (4). In more recent studies (3), sediment bound phosphorus (P) has been shown to be the major form of phosphorus transported from agricultural watersheds into Lake Erie. A recent final report of the Corps of Engineers' "Lake Erie Wastewater Management Study" estimated that 66% of nonpoint P loadings originate from agricultural land (7). Nelson and co-workers in the Black Creek Study (3) showed that 93% of the total P delivered to the Maumee River was sediment-bound P. Reduction of sediment concentration of runoff from agricultural watersheds is clearly needed if water quality is to be significantly improved. In the study reported in this paper effect of raindrop impact and surface runoff in detaching and transporting soil material was determined. This is important in order to develop land treatment measures that will effectively reduce sediment yields from agricultural watersheds.

Materials and Methods

This study was a part of the EPA-supported Black Creek Watershed Sedimentation Study located in Allen County, Indiana (3).

ARS-Purdue rainfall simulator (6) tests were conducted at four locations during the months of July and August, 1974. These four locations consisted of four distinct soils, identified in Table 1, which were representative of over 80% of the major soil capability units contained in the 4800 ha Black Creek Study Area.

All test locations, which were in rowcrops the prior year, were moldboard plowed in early spring and disked twice immediately prior to conducting tests. The final disking was performed up and down the dominant slope. Metal borders were installed to delineate runoff plots 1.9 m wide and 10.7 m long at all locations. The simulated rain used in the tests closely approximated the drop-size distribution of natural rain and approached 80% of the kinetic energy of natural rain. Inflow was also simulated by introducing water at the upper end of the plots using two rates, one and two times the equilibrium runoff rate induced by rainfall. The four tests were all run sequentially on the same plot at each loca-

Table 1. *Identification of Test Locations*

Soil Phase	Classification	Percent Slope
Haskins loam	Aeric Ochraqualf; fine-loamy, mixed mesic	0.2
Nappanee clay loam	Aeric Ochraqualf; fine, illitic, mesic	0.7
Hoytville silty clay	Mollic Ochraqualf; fine, illitic, mesic	0.5
Morley clay loam	Typic Hapludalf; fine, illitic, mesic	5.1

tion. The first test was separated by the second, third and fourth tests by approximately 24 hours.

The test sequence was as follows:

First Test (Rain vs. Inflow Rate 1)—Simulated rain was applied for 45 minutes at 6.35 $cmhr^{-1}$, after which time the rain was turned off and inflow was introduced at the upper end of the plot for 15 minutes at approximately the same runoff rate as was occurring just before rainfall was cut off. This allowed a direct comparison of rain-induced runoff and inflow-induced runoff without rain on the sediment concentration of the runoff. At all four locations, the runoff from rainfall alone had reached equilibrium several minutes prior to the end of the 45 minute rainfall period. The inflow at the upper end of the plot was delivered by means of a gated aluminum pipe.

Second Test (Rain + Inflow Rate 1)—Thirty minutes of rainfall was applied at 6.35 $chmr^{-1}$ and inflow was simultaneously introduced at the upper end of the plot to produce twice the runoff achieved at the steady-state condition which would have occurred from rainfall-induced runoff alone. Once rainfall-induced equilibrium runoff was achieved, the rate remained essentially the same because of the somewhat stable surface seal produced. This second test enabled us to answer two additional questions. First, what effect does increased runoff rate (thus increased depth of water on the plot surface) have on the sediment concentration of runoff? Second, what effect does slope length have on the sediment concentration? It is assumed that doubling the runoff rate in essence doubles the effective plot length.

Third Test (Inflow Rate 1 vs Inflow Rate 2)—Inflow Rate 1 was applied for 15 minutes, followed by Inflow Rate 2 for another 15 minutes. The effect of doubling the runoff rate on sediment concentration could now be compared without considering the effects of rainfall energy. Inflow Rate 2 essentially doubled the effective plot length.

Fourth Test (Rain + Inflow Rate 2)—Simulated rain was applied at 6.35 $cmhr^{-1}$ for fifteen minutes, while simultaneously adding the inflow required to produce three times the steady-state runoff rate from rainfall alone. In effect, the slope length was tripled. This test expanded the information gathered from the second test showing how an even greater depth of water on the plot surface would effect the sediment concentration of runoff.

Data collected from these studies included: a) runoff hydrographs from which runoff rates were determined and b) 1% aliquot samples of runoff taken approximately every five minutes from which percent sediment was determined. Only the segments of hydrographs where both runoff and sediment concentrations were either approaching or were at equilibrium were used.

Results and Discussion

The runoff rate and sediment concentration data for all four test locations are given in Table 2. In the first test approximately 75% of the 6.35 $cmhr^{-1}$ rainfall application was lost as runoff at the time sediment concentrations were measured at all four test locations. This was caused by the action of the raindrops in developing a slowly permeable surface seal. Once this surface seal was formed, it became the dominant factor restricting infiltration. Earlier simulated rainfall tests under conventional seedbed conditions showed that a relatively stable surface seal occurred on a broad range of soils within the first twenty minutes of rain application (5). It was assumed that the surface seal remained fairly stable through the rest of the test sequences.

TABLE 2. *The effect of raindrop impact and slope length on sediment concentration of runoff*

Soil Phase	Test Sequence	Runoff Rate[1] $cm hr^{-1}$	Sediment Concentrations %
Haskins loam	1st Test - Rain	4.8	1.18
	Inflow Rate 1	4.8	0.18
	2nd Test - Rain + Inflow Rate 1	9.6	0.91
	3rd Test - Inflow Rate 1	4.8	0.40
	Inflow Rate 2	9.6	0.48
	4th Test - Rain + Inflow Rate 2	—	—
Nappanee clay loam	1st Test - Rain	4.3	0.98
	Inflow Rate 1	4.3	0.08
	2nd Test - Rain + Inflow Rate 1	8.6	0.54
	3rd Test - Inflow Rate 1	4.3	0.02
	Inflow Rate 2	8.6	0.03
	4th Test - Rain + Inflow Rate 2	12.9	0.30
Hoytville silty clay	1st Test - Rain	5.3	1.37
	Inflow Rate 1	5.3	0.14
	2nd Test - Rain + Inflow Rate 1	10.6	0.49
	3rd Test - Inflow Rate 1	5.3	0.09
	Inflow Rate 2	10.6	0.09
	4th Test - Rain + Inflow Rate 2	15.9	0.29
Morley clay loam	1st Test - Rain	5.3	3.81
	Inflow Rate 1	5.3	0.42
	2nd Test - Rain + Inflow Rate 1	10.6	2.43
	3rd Test - Inflow Rate 1	5.3	0.34
	Inflow Rate 2	10.6	0.41
	4th Test - Rain + Inflow Rate 2	15.9	2.92

[1]Runoff rates are the average runoff rate measured over a 30 minute rainfall period after a surface seal was well established and runoff had reached an equilibrium condition.

Haskins loam (0.2% slope)

Raindrop energy was a major force affecting sediment concentration for Haskins loam since inflow-induced runoff in the first test was only 15% of that for rain-induced runoff. This conclusion was further supported by the results of the second test, where the re-introduction of rainfall in conjunction with inflow dramatically increased sediment concentration compared to inflow alone. This value (.91%) was slightly lower than the value (1.18%) for rain alone in the first test which may suggest that the increased runoff from the inflow cushioned raindrop impact slightly and thus, its detachment capability, a conclusion that could have some merit on nearly level topography.

The third test sequence showed that doubling inflow alone increased sediment concentration only slightly (.40 to .48%). This suggests that increasing slope length had only a slight effect on sediment concentration at this site. Insufficient water was available to complete the fourth test on the Haskins soil.

Nappanee clay loam (0.7% slope)

The case for raindrop energy being the principal force affecting sediment concentration is even stronger for the Nappanee soil than for the Haskins soil. Results of the first test show that the value for inflow-induced runoff to be only 8% of that for rain-induced runoff. Again a dramatic increase in sediment concentration occurred when rain was included with inflow in the second test sequence.

The cushioning effect of the increased runoff depth from the inflow, as in the case of the Haskins soil was responsible for the lower sediment concentration with rain plus inflow compared to rain alone (0.54% vs 0.98%) since this soil was also situated on essentially level topography.

The third test further strengthens the evidence that inflow-induced runoff has little effect on sediment concentration of nearly level soils at least for the flow rates that were used. Values for both the single and double rates of inflow were essentially the same and were extremely low. Evidently, runoff velocity on this nearly level soil was not sufficient to detach or transport significant amounts of sediment.

In the fourth test, where rain was added to the double inflow rate, the sediment concentration was only about 30% of that resulting from rain alone. This latter comparison supports the concept that increased runoff depth cushions the impact of raindrops. Also, tripling the slope length as simulated in the fourth test appeared to have limited influence on sediment concentration from this nearly level soil.

Hoytville silty clay (0.5% slope)

This soil responded similarly to the Nappanee and Haskins soils. Results from the first test showed the sediment concentration from inflow-induced runoff to be only 10% of that for rain-induced runoff. Also results from the second test showed that the addition of rain to inflow increased sediment concentration, but the value was appreciably lower than with rain alone. In the third test, no difference in the sediment concentrations was noted when inflow amount was doubled. Runoff from nearly level land has extremely limited soil detachment and transport capacity. In the fourth test, sediment concentration from the double inflow rate plus rain was only 21% of that from rain alone. Again the increased flow depth reduced the detachment energy of the rainfall.

Morley clay loam (5.1% slope)

The Morley soil site was the only test location that had appreciable slope. This slope markedly influenced the sediment concentration. For example, in the first test with rain alone, the sediment concentration was approximately three times that of the other nearly level sites. This result was generally consistent in all of the tests where rain was included as part of the treatment. Evidently, the greater slope increased the runoff velocity and its sediment transport capacity sufficiently to remove a much greater proportion of soil detached by raindrop impact. Another factor that could be involved is the absence of surface ponding (which occurred on the nearly level soils, thus providing protection from raindrop impact) on the more sloping Morley site.

Although runoff velocity obviously increased at this site because of steeper slope, it still lacked sufficient energy to detach soil particles in amounts which would result in high sediment concentrations. Raindrop impact was needed, even on a 5% slope, to detach sufficient soil to create a serious problem. Results from the first test showed sediment concentration from inflow-induced runoff to be only 11% of that for rain-induced runoff while the inclusion of rain with inflow in the second test dramatically increased the sediment concentration. It was still only 64% of the value for rain alone. This result suggests that slope length has some impact on sediment concentration, but that raindrop impact still remains the major force for these rainfall and runoff rates. However, when the slope length is doubled without rain, sediment concentration is affected very little. Results from the fourth test showed that the additional flow volume increased the sediment concentration when compared with the second test. This increase did not occur on the nearly level sites with the Nappanee and Hoytville soils.

Summary

The results of the simulated rainfall and inflow studies conducted on four soils in the Black Creek Watershed in Allen County, Indiana, show rainfall energy to be the major factor affecting sediment concentration of runoff from agricultural soils in a seedbed condition. Sediment concentration of rainfall-induced runoff ranged from 7 to 12 times that of inflow-induced runoff for all the soils. In the study, doubling or tripling the selected inflow to simulate increased slope length had little influence on sediment concentration. However, slope steepness did influence sediment concentration. On the test site having the 5.1% slope, sediment concentrations approximately three times those from the other three nearly level test sites occurred whether runoff was rainfall-induced, inflow induced, or a combination of both. These results demonstrate again the necessity of protecting the soil surface from raindrop impact in order to effectively reduce sediment concentrations of runoff which will, in turn, maintain soil productivity and enhance water quality.

Acknowledgment

This study was supported in part by a grant from Region V, Environmental Protection Agency, Chicago, Illinois.

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