Determination of Soil Erosion Runoff using a Developed Laboratory Rainfall Simulator

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ABSTRACT
Using a developed rainfall simulator, soil erosion was studied in three representative soils in Auchi, Southern part of Nigeria. The runoff water and the quantities of the eroded sediments were measured with respect to soil type, slope and vegetal cover. Erosion from the simulated storm was greatly reduced by vegetative cover, declining from (3.32 - 4.48)*$10^{-3}m^3$ for the exposed soil to (1.05 - 1.21)*$10^{-3}m^3$, for the one covered with vegetation due to interception of raindrop by the leaves. However, increase in slope from 5^o through 15^o increased the runoff and quantities of eroded sediments slightly from (4.82)*$10^{-3}m^3$ and 0.850 kg to (3.98)*$10^{-3}m^3$ and 1.439kg respectively. The quantity of runoff for the three types of soil considered was more in sample C (sandy loam) with a value of (3.32)*$10^{-3}m^3$ than the other soil types, sample A (silty clay) and sample B (clay soil) with runoff values of 4.48 and 4.38*($10^{-3}m^3$ respectively.
Keywords: soil erosion; slope; soil type; vegetation; rainfall simulator

1.0 INTRODUCTION

One of the greatest problems facing man and his environment is soil erosion. This is the wearing away of soil particles either by wind action or water action. Worst affected are farmers who cultivate soil for the use of their crops.

Erosion has constituted a nuisance to the environment in the areas of pollution, public health hazard and environmental degradation. According to Beasley (1972), an estimated four billion tons of soil was lost to soil erosion every year in the United States of America thereby threatening the lives of some inhabitants.

Pollution is another effect of soil erosion. It is a common practice that chemicals and pesticides are washed down slope into streams thereby killing fishes and making the stream water unsafe for human consumption. Soil erosion is influenced by the type of soil, vegetation and slope. The soil properties influencing erosion by water are the infiltration capacity of the soil and the resistance of the soil to dispersion and transportation of soil perfectly during rainfall.

Erosion is influenced by the type of soil, that is, sandy soil, loamy soil and clay soil. The soil properties influencing erosion by water are infiltration rate of the soil and the resistance of soil to dispersion and erosion during erosion during rainfall.

Sandy soil has properties that are coarse and loosely packed together. This determines the size of the infiltration rate. Infiltration is the ability of water molecules to soak into the soil.

Since the particles are not compacted together, water easily finds its way into the soil thereby resulting to little or no runoff depending on initial moisture content of the soil and the rainfall intensity.

Loamy soil has its particles much more compacted than sandy soil. Hence, the infiltration rate decreases with an increase in runoff. Clay soil on the other hand has well closely packed particles with little pores. There is therefore a greater decrease in infiltration rate and this type of soil produces the greatest runoff resulting from erosion. This is usually the case because the water which finds it difficult to percolate the soil has to find an alternative exit route.

Several other factors affecting soil erosion are vegetation, topography, amount of rainfall intensity and the nature of the soil.

1.2 Justification

Attempts have been made on the field to prepare some plots to carry out test on soil erosion so as to monitor the processes and the rates of runoff and the amount of soil loss over a whole slope. This involves a great deal of survey works and money to purchase machines which will be used in levelling either by filling the depression or by cutting the ground surface. In view of these problems, a laboratory rainfall simulator was developed and used to carry out experiment on soil erosion.

1.3 Objectives of The study

The objective of the (i)To simulate rainfall in the rainfall simulator developed for performing soil erosion experiments.

2. MATERIALS AND METHODS

2.1 Description of the Rainfall Simulator

The materials used for the construction of the rainfall simulator were over 90 per cent wood. Wood was chosen because of its lighter weight when compared with metal. Apart from the runoff collector, hose and the bucket which are plastic, all the others are wood except the base of the simulator which is made of metal with 475 droppers (openings) of 5mm diameter

Figure 1: A pictorial view of the developed rainfall simulator used for the experiment

drilled on it and spaced 20mm apart. This is in accordance to Baver *et al* (1972) who reported that raindrop vary in size up to about 5mm.The simulator has a weir constructed across it to distribute the water uniformly down its entire slope of 850mm. The soil bin was constructed in such a way that its angle can be adjusted by placing wooden cube(s) on top of each other at the edge to give angles of 5 ^{o}, 10^{o} and 15^{e} slope. It is on this that the soil to be tested was placed. The plastic runoff collector was placed on the floor just below the soil bin to collect the runoff during the experiment.

2.2 Soil Test

Three (3) different soil samples were collected from three different locations in Auchi, Southern part of Nigeria and designated sample A, sample B and sample C. Each soil sample was oven dried for 24hours and quartered Issam and Antoine (2007)

Quartering involves forming the soil into a heap, using hand to cut across its centre thereby dividing it into two(2) equal parts, the two parts were further cut into four(4) parts and the two opposite parts were then collected. This was to ensure equal representation of the soil. During the process of quartering, all the foreign materials were removed from the soil samples.

The quartered soil samples were then mortared using a laboratory mortar and pestle. The soil samples were then weighed along with their containers and the weight of the empty containers was also taken. In order to classify the soil type, the weighed soil samples were then poured on Tyler sieves and then shaken with a Rotap machine for about five (5) minutes. The weight of each sieve and the soil retained on them were also taken. The percentage values of soil retained on each sieve were then plotted on a soil textural triangle as described by Issam and Antoine (2007) and Luthin, (1973).to ascertain the type of soil.

2.3The Experimental Run

The already ascertained soil types were then air dried, mortared, sieved and each put on the soil bin and subjected to five minutes of simulated rainfall. The eroded and runoff materials were then collected. In trying to study the effect of vegetation on soil loss fresh *Clorophora Odoratum* leaves were cut from the bush and piled on top of the soil contained on the soil bin up to a height of 5mm. This was then subjected to a five minutes simulated rainfall and the quantities of runoff for each soil type were collected and measured. Also the effect of slope on soil erosion was carried out using only sample A. The eroded sediments on the runoff were sieved using filters and the resultant sediments dried in the oven at a temperature of 100^{o}c for a period of 24 hours.

3. RESULTS AND DISCUSSIONS

3.1Determination of the Soil Type

Sieve analysis was carried out on the three soil samples to ascertain their soil types using a textural triangle used by soil scientists for establishing the soil type (Luthin, 1973).

Sample A
Wight of empty pan=0.220kg
Weight of pan + soil=1.993kg
Weight of soil =(1.993-0.220)kg =1.773kg

Table 1: Particle Size Analysis of Sample A

Sieve No(mm)	Weight of sieve(kg)	Weight of sieve+soil retained(kg)	Weight of soil retained(kg)	Percentage of soil retained%
13.20	0.580	0.580	0.000	0.000
6.7	0.466	0.486	0.020	1.280
4.75	0.500	0.524	0.025	1.410
2.36	0.434	0.508	0.074	4.175
1.70	0.416	0.774	0.358	20.19
1.18	0.397	0.849	0.452	25.49
850µm	0.378	0.830	0.160	9.020
600µm	0.365	0.706	0.341	19.23
Pan	0.450	0.793	0.343	19.36

Sample B
Weight of empty pan =9.220
Weight of pan + soil = 1.408kg
Weight of soil = (1.506-0.220)kg = 1.286kg

Table 2: Particle Size Analysis of Sample B

Sieve No(mm)	Weight of sieve(kg)	Weight of sieve+soil retained(kg)	Weight of soil retained(kg)	Percentage of soil retained%
13.2	0.580	0.580	0.000	0.000
6.7	0.466	0.550	0.084	6.500
4.75	0.500	0.610	0.110	8.570
2.36	0.434	0.547	0.113	8.750
1.70	0.416	0.503	0.087	6.720
1.18	0.397	0.454	0.057	4.460
850µm	0.378	0.545	0.167	13.066
600µm	0.365	0.097	0.332	25.850
Pan	0.450	0.786	0.336	26.090

Sample C
Weight of empty pan = 0.220kg
Weight of pan + soil sample = 1.719kg
Weight of soil = 1.499kg

Table 3 Particle Size Analysis of Sample C

Sieve No(mm)	Weight of sieve(kg)	Weight of sieve+ container(kg)	Weight of soil retained(kg)	Percentage of soil retained(%)
13.20	0.580	0.929	0.349	23.28
6.70	0.466	0.789	0.323	21.55
4.75	0.500	0.680	0.201	13.41
2.36	0.434	0.639	0.205	13.68
1.70	0.416	0.517	0.101	6.738
1.18	0.397	0.519	0.122	8.139
850µm	0.378	0.441	0.063	4.203
600µm	0.365	0.417	0.052	3.469
pan	0.450	0.533	0.083	5.537

Tables 1, 2 and 3 above show the particle size analysis of samples A, B and C respectively while Table 4 below shows the summary of percentages of sand, silt and clay for all the three soil samples considered.

Table 4: Summary of percentages of sand, silt and clay of the three soil samples.

	Sample A	Sample B	Sample C
Sand	6.71	23.82	71.92
Silt	45.68	11.18	14.92
Clay	47.61	65.00	13.12

Having plotted the values in table 4 on soil textural triangle, Sample A was found to be silty clay, sample B, clay while sample C was sandy loam.

Table 5: Effect of soil type on soil erosion using a flat surface.

	sample A (silty clay)		*Sample B (clay soil)*		*Sample C (sandy loam)*	
Trials	*Quantity of runoff X10^{-3}m3*	*Mass of eroded materials(kg)*	*Quantity of runoff X10^{-3}m3*	*Mass of eroded materials (kg)*	*Quantity of runoff X10^{-3}m3*	*Mass of eroded materials(kg)*
1	4.30	0.282	4.55	0.217	3.10	0.093
2	4.65	0.241	4.60	0.228	3.25	0.82
3	4.50	0.267	4.20	0.239	3.60	0.076
Average	4.48	0.263	4.38	4.38	3.32	0.084

Table 6: Effect of slope on soil erosion using only sample A (silty clay)

	5% slope		10% slope		15% slope	
Trials	Quantity of runoff (x10^{-3} m3)	Mass of eroded materials(kg)	Quantity of runoff(f x10 $^{-3}$m3	Mass of eroded materials (kg)	Quantity of runoff(x10^{-3}m3)	Mass of eroded materials(kg)
1	4.75	0.982	4.30	1.255	4.00	1.450
2	4.98	0.995	4.65	1.330	3.60	1.365
3	4.75	0.872	3.90	1.600	4.30	1.520
Average	4.82	0.850	4.28	1.375	3.98	1.439

Table7: Effect of vegetal cover(*Chlorophora Odoratum*) on soil erosion

	Quantity of runoff X10^{-3}m3	Mass of eroded material(kg) of sample A	Quantity of runoff X10^{-3}m3	Mass of eroded material(kg) of sample B	Quantity of runoff X10^{-3}m3	Mass of eroded material(kg) of sample C
Trials						
1	1.310	0.152	1.110	0.094	1.020	0.043
2	1.240	0.136	1.140	0.089	1.120	0.047
3	1.090	0.147	1.170	0.079	1.020	0.039
Average	1.210.	0.145	1.140	0.087	1.050	0.043

The results of experiment on soil erosion loss for flat surface (0^o slope), as shown inTable 5, shows that soil loss for a soil sample A (silty clay) was more than the soil loss for soil sample B (clay) and sample C (sandy loam). This means that large soil particles reduce surface runoff as infiltration rate increases which are in agreement with Collinet and Valentine (1998). Soil losses as shown in Table 7 for the three soil samples under vegetal cover were lesser than the soil loss for the exposed soil surface. This may be due to due to the interception of raindrop.

Vegetal cover is the most dominant factor determining runoff and conforms with the results obtained by Karnieli and Ben-Asher (1993). Martnez *et al.* (1998), Sharifi *et al* (2004), Katrien *et al.* (2006) and Armando *et al* (2007). The mass of sediments eroded as shown in Table 6 for the slope considered have slight changes in their values, this slight effect of land slope could be related to short length (850mm) of slopes when working with small plots. However, the mass of eroded sediments for 15^o, 10^o and 5^o slope increases slightly in that order. This slight effect of land slope occurs when working small plots (850mm). This corresponds with the results obtained by Vahabi and Ghafouri (2009).

4. CONCLUSION

Soil erosion losses using a rainfall simulator may not be a true representation of what is happening on the field with a natural rainfall because the movement of soil from the field may destroy its natural structure. Thus, results of erosion studies with a rainfall simulator may be different from that of a natural rainfall for the same type of soil. From the experiments carried out, soil losses were greater with a sloppy land than that of a flat land and keeps on increasing as the angle of slope increases. The soil loss for a covered soil with vegetation is less than for an exposed one while erosion losses were greater in a soil that contains clay particles making infiltration into it difficult due to its compact nature of the particles. The runoff in sandy loam soils is more than clay and silty clay soils. Hence, slope, vegetation and soil type affect soil erosion.

REFERENCES

Armando M.G., Gerard V., Veerle, P. Jean, Z. Edwin and C. Felipe (2007). Runoff generation in a degraded Andean ecosystem. : Interaction of vegetation cover and land use. CATENA, 71: 357-370.

Beasley R.P. (1972). Erosion and sediment pollution control. Iowa University Press. 1-105.

Collinet J. And Valentin C. (1998). Evaluation of factors affecting water erosion in West Africa using a rainfall simulator. Challenges in African Hydrology and water Resources (proceedings of the Harare symposium, JAHS NO 144.

Issam I. Bashour and Antoine H. Sayegh (2007). Methods Of Analysis For Soils

Katrien D., N. Jan, R. Dick, H. Mitiku, M. Bart and D. Seppe (2006). Runoff on slopes with restoring vegetation.: A case study from the Tigray highlands, Ethiopia. J. Hydrol., 331: 219-241.

Kernieli A. and J.Been-Asher (1993). A daily runoff simulation in semi-Arid water sheds based on deficit calculations. J. Hydrology. Vol. 149: 9-25.

Luthin, J.N. (1973) 'Drainage Engineering', Robert E.K New York. 3rd Edition. Pp 1-202.

MartAnez-Mena, M. J. Albaladejo and V.M. Castillo (1998). Factors influencing surface runoff generation in a mediterrranean semi-Arid environment, Chicamo watershed, SE Spain. Hydrol. Procisses. J. 12: 741-754.

Of Arid And Semi-Arid Regions. Food and Agriculture Organization of the United Nations Rome,pp 22.

Sharifi F., S. Safarpour, S.A. Ayoubzaden and J. Vaakilpour, (2004). An investigation of factors affecting runoff generation in arid and semi arid area using simulation and rainfall runoff data. Iranian J. Natural Res., 57: 33-45.

Vahabi J. And M. Ghafouri (2009). Determination of runoff threshold using rainfall simulation in the Southern Aborz range. Sci. 3: 193-201

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