The Effect of Rainfall on Aggregate Stability and Splash Erosion on Some Agricultural Soils of Borno State, Nigeria

Bala B. Jingi, Usman D. Danladi, Abdulkadir S. Ahmed, and Yahaya Abubakar

Department of Agricultural and Environmental Engineering, Federal University of Technology, Yola, Adamawa State, Nigeria

Abstract

The amount of splash and aggregate stability of some agricultural soils were investigated with respect to rainfall duration. The soil samples were graded in aggregate sizes of 2.36, 3.35 and 6.70 mm, respectively. Energy in the form of water drops (3 mm diameter) falling from a height of 2.65 m was applied, using rainfall simulators with rainfall intensity of 228.6 m/hr at an interval of 5 min. The amount of splash was found to vary for clay soil from 3.06 to 4.46 g/cm (2.36 mm), 4.08 to 5.38 g/cm^2 (3.35 mm), and 6.03 to 7.43 g/cm^2 (6.70 mm), while for sandy clay, it varies from 2.72 to 4.02 g/cm^2 (2.36 mm), 3.09 to 4.48 g/cm^2 (3.35 mm) and 5.06 to 6.62 g/cm^2 (6.70 mm), respectively. Aggregate stability was found to vary for clay at 11.02% moisture content from 4.44 to 3.04% (2.36 mm), 3.42 to 2.12%. (3.35 mm) and 1.47 to 0.07% (6.70 mm), while it varies for sandy clay at 10.68% moisture content from 4.78 to 3.48% (2.3 mm), 4.41 to 3.02% (3.35 mm) and 2.44 to 0.88% (6.70 mm), respectively.

Keywords*: Clay, sand, moisture content, amount of splash, aggregate stability, rainfall duration.*

1. Introduction

The soil is a complex system made of solid, liquid and gaseous materials. The soil phase is made of minerals and organic particles, the liquid phase is composed of the solutions of various salts, and the gaseous phase is represented by air (Dregne 1976). These three phases interact, hence the soil is dynamic. The solid phase is essential in understanding many of the practical agricultural and environmental problems and the external stresses brought about by rainfall impact (Hillel 1980).

Soil aggregate structures can be characterized quantitatively by measuring the size of their particles, such measurements are usually carried out when samples are subjected to change in moisture content and are used as an index of stability (Palmer 1965). It is therefore important to determine the stability of aggregates of different sizes as they might be subjected to different physical and biological factors, which may render the soil unproductive and susceptible to erosion.

The stability of aggregate structures refers to the resistance that the soil aggregates offer to the disintegration influence of water and mechanical manipulation. In regions where agriculture is highly mechanized, soils are cultivated and left exposed to external forces. High rainfall intensity might subject the soil structure to detritions by the action of rainfall which consequently results in erosion (Greenland 1977). Intense rainfall destroys the granulation and the open structure of the top few centimeters or more of the soil to form a dense impervious surface called crust. The erosive capability of the falling mass of water depends on the energy per unit area of the drop. It is the application of this energy in the form of a rain drop impact that accounts for the greatest part of the dispersion of soil particles (Ellison 1944) on some terrains, the wash off soil losses alone account for only a small part of the overall damage from a heavy rain, the rest of the damage is attributed to splash (Laws 1940).

In semi-arid regions, like Borno State, Nigeria, where agricultural soils are light and highly susceptible to compaction, it is very necessary to understand the aggregate breakdown due to rainfall. Because of the erratic nature of the rainfall in this region, it is often noticed that a short rainfall causes water logging in many areas, thus rendering the soil unproductive. This study could be useful in determining the type and time of cultivation practices needed for increased crop production. The objectives of the study where:

i. To determine the amount of splash at different rainfall durations for different aggregate sizes.
ii. To determine the aggregate stability of the different soil aggregate sizes.
iii. To apply regression analysis in order to obtain the best relationship between the amount of splash, aggregate stability and rainfall duration, and also for the purpose of making predictions.

2. Material and Methods

For this study, soil samples were obtained from Biu town, Ngala town, and the University of Maiduguri research farms in Borno State, Nigeria. The soil samples included sandy clay, clay and clay loam, respectively. Rainfall simulation sieves of different sizes and large rectangular containers for splash collection (cores) were among the materials used in this research work.

The soil samples of different aggregates were prepared to study the stability and amount of splash in sandy clay, clay and clay loaf, and the samples were subjected to rainfall of varying durations (between 5-30 minutes). The soil samples were sieved through various screens to form aggregate sizes of 2.36, 3.35 and 6.70 mm, respectively. A number of cores (9.7 cm diameter and 17.5 cm height) were used to collect the splash. The samples were placed to cover the top 5 cm depth of the core and water underlain by 12.5 cm depth of compacted soil sample, each subjected to 25 blows (619 kPa) of the proctor type compaction rammer. At the beginning of each run, the splash collecting container (80.5 x 72.8 x 14.3 cm) was placed beneath the simulator. Two cores, each containing the samples, were then placed inside the container and were exposed to simulated rainfall. Energy in the form of water drops (3 mm diameter) falling from a height of 2.65 m was applied to each sample aggregate, six runs were carried out, lasting 5-30 minutes.

The amounts of splash were determined by collecting splash materials, which were allowed to settle down at the base of the container. The slurry (splashed material) was washed and oven dried before weighing. Rainfall intensity (228.6 mm/hr) and drop size were uniform throughout the study.

3. Data Analysis

Statistical model based on a linear equation was developed to fit the data collected in the study. The model was using a linear fit (LINFIT):

$$y = mx + c. \qquad (1)$$

Other statistical parameters of data analysis include: coefficient of correlation (r) which gives the degree of association; and coefficient of determination (R) which evaluates the degree of association between observed data and predicted values.

The simulated rainfall intensity (I) was determined using the following equation:

$$I = V / (DT), \qquad (2)$$

where: D = depth of rainfall (mm); T= duration of rainfall (hr); and V = average volume of water collected (mm^3).

The aggregate stability was determined using Palmer's approach (Palmer 1965):

$$\% S.A. = \frac{(100\ Wt_{\text{retained}} - Wt_{\text{stone}})}{(Wt_{\text{total sample}} - Wt_{\text{store}})}, \qquad (3)$$

where: $S.A.$ = aggregate stability; Wt = weight.

4. Results and Discussion

4.1 Amount of Splash and Rainfall Duration

Table 1 shows the amount of splash and the duration of rainfall. It is observed that the amount of splash increased with the increase in rainfall duration for sandy clay and clay soil for the three aggregate sizes of 2.30, 3.35 and 6.70

mm, respectively. The observed characteristics of clay may serve as indicators for detecting the physical instability of slowly permeable soils as the depth of rainfall increases with rainfall duration. The cumulative effect of rainfall was responsible for a corresponding increase in rainfall depth with time, which makes the soil to become more susceptible to detachment and splashing as the soil water content increases with time during rainfall. Results could be obtained from the investigation on sandy loam because the only aggregate formed splashed away under rainfall duration of 5 min due to the low percentage of clay in the soil.

Table 1. Amount of splash for sandy clay and clay soil aggregates.

Duration of rainfall (mm)	Amount of splash (g/cm2)	
	Sandy clay	Clay
2.36 mm		
5	2.72	3.06
10	2.94	3.18
15	3.08	3.32
20	3.41	3.56
25	3.72	3.04
30	4.02	4.46
3.35 mm		
5	3.09	4.08
10	3.22	4.19
15	3.38	4.33
20	3.50	4.42
25	4.02	4.98
30	4.48	5.38
6.70 mm		
5	5.06	6.03
10	5.56	6.20
15	5.62	6.33
20	5.80	6.43
25	6.20	6.69
30	6.62	7.43

4.2 Aggregate Stability and Rainfall Duration

Table 2 shows the results of aggregate stability of sandy clay and clay soil of the different aggregate sizes (2.36, 3.35 and 6.70 mm). It was observed from the results that the increase in rainfall duration decreases the aggregate stability of the soils. However, the decrease in stability was greater for clay than sandy clay soil, which indicates that sandy clay can withstand more rainfall. The decrease in the stability of aggregates as a result of dry weight of soil thrown out of the core was due to cohesion of surface particles. Although soil erosion occurs in all soil types, it was observed in this study that there is a high resistance to erosion due to an increase in cohesion as the aggregate size reduces. For larger aggregate sizes, more time is required to resist erosion through cohesion of surface particles. Thus, aggregate sizes greater than 2 mm are found to be less stable and susceptible to breakdown by raindrop.

Table 2. Aggregate stability for sandy clay and clay.

Duration of rainfall (mm)	Aggregate stability (%)	
	Sandy clay (11.02% moisture content)	Clay (10.68% moisture content)
2.36 mm		
5	4.78	4.44
10	4.56	4.32
15	4.42	4.18
20	4.09	3.94
25	3.78	3.46
30	3.48	3.04
3.35 mm		
5	4.41	3.42
10	4.28	3.31
15	4.12	3.71
20	4.00	3.08
25	3.48	2.52
30	3.02	2.12
6.70 mm		
5	2.44	1.47
10	1.94	1.30
15	1.88	1.70
20	1.70	1.07
25	1.30	0.54
30	0.88	0.07

4.3 Linear Regression Equations

The simple linear regression equations obtained when the amount of splash and aggregate stability were regressed on duration of rainfall for sandy clay and clay soils of 2.36, 3.35 and 6.70 mm sizes, respectively, were presented in Table 3. It was observed that within the same aggregate size, the slope of the graph of the amount of splash vs. rainfall duration was steeper than the corresponding aggregate stability, for which the slopes of the different sizes for the amount of splash and aggregate stability vs. rainfall duration where slightly significantly different from one another at 5% level of significance.

Table 3. Linear regression equations of the amount of splash and aggregate stability on rainfall duration.

Regression equations	*R*	Aggregate size (mm)
Sandy clay soil		
As = 0.05*x* + 2.4	0.9652	2.36
Sa = -0.05*x* +5.10	-0.9926	
As = 0.05*x* + 2.70	0.9534	3.35
Sa = -0.05*x* + 4.83	-0.9534	
As = 0.06*x* + 4.82	0.9826	6.70
Sa = -0.06*x* + 2.70	-0.9827	
Clay soil		
As = 0.06*x* + 2.58	0.8987	2.36
Sa = -0.06*x* + 4.49	-0.9681	
As = 0.05*x* + 3.67	0.9405	3.35
Sa = -0.05*x* + 3.84	-0.9415	
As = 0.05*x* + 5.63	0.9475	6.70
Sa = -0.05*x* + 1.90	-0.9538	

Note: *As* = amount of splash; *Sa* = aggregate stability.

5. Conclusion

The following conclusions can be drawn from the study:

i. The size of aggregate soils and the rainfall duration affect the splash and the stability of the soil.

ii. The aggregate stability of sandy loam could not be established as the soil splashed away after a rainfall drop for 5 min.

iii. The amount of splash increased with rainfall duration, indicating a decrease in the stability of the soil aggregate.

iv. For large size aggregates, the intake rate is high for a larger period, thus reducing runoff and total erosion.

v. Linear regression equation can be used to describe the relationship between the amount of splash and the aggregate stability of soil.

6. References

Dregne, H.E. 1976. Developments in soil science. 6: Soils of arid regions. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands.

Ellison, W.D. 1944. Studies of raindrop erosion. Agricultural Engineering 25: 131-6, 181-2.

Greenland, D.J. 1977. The magnitude and importance of the problem. *In*: D.J. Greenland; and R. Lal (eds.) Soil conservation and management in the humid tropics. John Wiley & Sons, a Wiley Interscience Publication, Chichester, West Sussex, England, UK, pp. 3-7.

Hillel, D.J. 1980. Aggregate stability. *In*: Fundamentals of soil physics. Academic Press, Inc., New York, NY, USA, pp. 105-11.

Laws, J.O. 1940. Recent studies in raindrops and erosion. Agricultural Engineering 21(11): 431-3.

Palmer, R.S. 1965. Waterdrop impact forces. Transactions of the American Society of Agricultural Engineering (ASAE) 8(1): 69-70, 72.