UDC 631.4 → 632.125

Translated from:
Pochvovedeniye, 1988, No. 2: 122-129

SOME PATTERNS OF SOIL EROSION IN CUBA

G. L. SHCHEPASHCHENKO, M. RIVEROL and N. CALSADA, V. V. Dokuchayev Soil Institute

Soil erosion studies in Cuba have shown that the separating capacity of tropical storms depends on the kinetic energy of rain and on the content of soil aggregates >2 mm in diameter The separation of soil particles in the course of sheet erosion is due mainly to the raindrops and to the migration of the detached soil particles caused by the raindrops and surface runoff. The effect of topography on erosion is manifested by the slope steepness and form.

Soil erosion in Cuba is significantly different from that in temperate regions It deviates from the well-knovn patterns of the washing away of soil and its redeposition in the course of erosion. For example, erosion on a straight slope does not increase downward, as Sobolev [7], Zaslavskiy [3], and many others have pointed out but rather upward, i.e., the slopes are more severely eroded near the summit than in the middle or lower part of the slopes. The relationship between erosion and slope length of equal steepness is not as clear as in a temperate climate. These features are due to the widespread occurrence in Cuba of sheet erosion during which raindrops play a major role.

Soil erosion in the tropics begins even before the surface runoff begins. The first raindrops falling on bare soil break down its structure and later, on rebounding from the soil surface, carry away the small particles and occasionally whole aggregates 1-2 mm in diameter. The detachment of soil particles from the main soil grass is the first stage of erosion. This process depends on many factors the most important of which are the nature of the precipitation and the proper ties of the soils themselves.

To study the separating capacity of rain, we conducted experiments with sprinkler irrigation. Studies were cone on different rainfall characteristics: drop size and the depth and intensity of rainfall. Experiments were carried out in Elli son pans [9] filled with sand passed through a 1 mm sieve. Sand was selected as the initial material because it is more homogeneous, does not stick, readily allows water to percolate, and does not become compact, as happens in experiments with soil. Thus, the amount of sand ejected from the pans by raindrop impact depends only on the rainfall parameters.

Results of variance analysis of the data obtained from sprinkling sand show that the depth of rainfall (representing 58% of the effect) and drop diameter (representing 26%) exert the greatest influence upon the separating capacity. Rainfall intensity has little or no effect on the amount of sand ejected from the pans. This situation is quite normal. Each falling drop detaches a certain amount of sand. The larger the drop, the more energy it has and the more work it accomplishes. Thus, the total amount of sand ejected from the pans depends only on the number and diameter of the drops and not at all on the time it took for the drops to fall. However, given the data on drop diameter and depth of rainfall, it is possible to calculate the kinetic energy of rain, which will serve as an integral index

 ISSN0038-5832/88/0004-0075$7.50/0

Table 1

Amount of soil ejected by raindrops from Ellison pans

Soil	Amount of soil, g
Washed sand (standard)	52±1.20
Yellow allitic-quartz loamy sand	46±l.25
Gray-cinnamon brown sandy loam	38±1.18
Cinnamon brown noncalcareous clay loam	21±0.75
Cinnamon brown calcareous clay loam	19±0.62
Humus-calcareous clay loam	20±0.70

Table 2

Correlation of soil losses in the course of splash erosion with certain soil physical and chemical properties

Index	r	T-Criterion	
		calculated	tabulated
Humus content, %	0.81	5.29	3.7
Calcium carbonate content, %	0.53	3.07	3.7
Absorbed calcium content, meq/100 g	0.87	7.06	3.7
$Si0_2/Fe_20_3$	0.33	1.78	3.7
Physical clay content, %	0.98	12.25	3.7
Dispersion factor, %	0.83	6.29	3.7
Content of aggregates > 0.25 mm, %	0.90	7.81	3.7
Content of aggregates > 1 mm, %	0.81	5.87	3.7
Content of aggregates > 2 mm, %	0.97	11.78	3.7

in evaluating its separating capacity. Kinetic energy (E_k) is calculated by the equation $E_k = 0.00005X\, ny^2$ [8], where X is the rainfall depth in mm; 0.00005 is a constant; n is the amount of rainfall with a given drop diameter; y is the final velocity of raindrops of a given diameter. Considering that drops of the same size were used in each of the experimental treatments the equation above can be written as follows: $E_k = 0.00005Xy^2$. In this case kinetic energy is expressed in joules. Regression analysis of sand losses during erosion and of data calculated using this formula also confirms the existence of a direct relationship between these indices, which is described by the equation $y = 2.169 + 0.0099X$, where X is E_k in joules and y is the sand loss in grams. Thus, the separating capacity of rain depends entirely on its kinetic energy.

To study the effect of soil conditions on splash erosion, soil samples were sprinkled with natural rain for 20 minutes. Five soil groups were studied: humus- calcareous, cinnamon-brown calcareous, cinnamon-brown noncalcareous, gray cinnamon- brown and yellow allitic-quartz soils. The data obtained show that even yellow allitic-quartz loamy sand is more stable than pure sand (Table 1). The other soils, medium and clay loam in texture, withstood even better the action of the raindrops.

The causes of the difference in stability of soils with respect to the action of the drops are the many indices and properties of soils responsible for their resistance to erosion. We studied the correlation between 9 soil properties and soil loss due to erosion (Table 2) and found that almost all (except the yellow allitic-quartz soil) more or less highly correlated with such resistance.

However, there is also a fairly close relationship between these indices. In fact, the more organic matter and physical clay there are in a soil, the better its structure and the more stable its aggregates in withstanding the destructive effects of raindrops.

Step-by-step regression analysis has shown that the resistance of soil to splash erosion can be judged from one of the indices—the content in the plow layer of water-stable aggregates >2 mm in diameter. A curvilinear relationship exists between this index and soil loss, which is described by the equation $y = 40.33 — 0.34X + \frac{58.64}{x}$. Thus, it can be said with certainty that the amount of soil separated in the course of splash erosion depends on the kinetic energy of rain and on the content in the soil plow layer of water-stable aggregates >2 mm in diameter.

It is generally known that on an ideally level surface in still air splashes of rebounding drops along with entrapped soil are dispersed in all directions to more or less the same distance. With large raindrops this distance is 90 cm [10]. Although the soil is shifted from one place to another, it is not transported far from its original location. On a slope, soil aggregates or their particles caught in a spray and falling down a slope, travel much farther from the point of contact of the raindrop with the soil than those in upslope sprays. The steeper the slope [6] the greater the difference.

On an ideally level straight slope, the amount of soil detached by raindrop impact and its transport rate are practically the same anywhere on the slope. However, the upper part of the slope near the summit is more eroded because elsewhere on the slope farther from the summit the soil carried away by the raindrops is compensated for by soil from higher up. The farther the part of the slope is from the summit, the more soil passes over it and the slower it is eroded. It is only near the summit that soil losses cannot be compensated. Thus, in the humid tropics the soil profile on lower parts of straight slopes is much thicker than in the middle and, especially on the upper part of the slope is contrast to temperate regions where the soils toward the bottom of slopes are most eroded. On slopes of different forms this pattern is disturbed because different parts of slopes are not equally steep. However, this occurs only on slopes with a sharp break in the surface. On gentle convex slopes, for example, the rate of transport of splash erosion products increases gradually downward as steepness increases. However, the degree of erosion does not increase proportionately with steepness because the somewhat higher soil loss from the middle of a slope on account of an increase in the "pace" of the drop and the resulting rate of transport of erosion products is compensated for by the soil it receives from above. On steep and short slopes, the middle parts are the most eroded because loss from the steep part of the slope is much higher and the soil it receives from above is not able to make up for the losses. On concave slopes, as in temperate climates, the upper part of a slope is even more severely eroded. Here the main pattern of splash erosion is further reinforced by an increased loss of soil due to its steeper upper part.

The slope length has the opposite effect on the rate of splash erosion. This can be seen from the following calculations. If the steepness and length of a straight slope are known, we can calculate how long it will take for a microvolume of soil to be transported from the crest to the base of the slope from the formula $f = \frac{L}{l}\Delta t$, where *L* is the slope length, *l* is the rainsplash distance, *t* is the time, and Δt is the time between falling drops. One can see from this equation that the longer the slope the longer it will take for a microvolume of soil to be transported beyond the slope.

The patterns described above are typical of "pure" splash erosion and are observed during the period from the beginning of rain to the start of surface runoff from a slope when the picture changes somewhat.

Many investigators do not attach much importance to splash erosion simply because they consider it a temporary phenomenon inasmuch as surface runoff during heavy tropical downpours occurs fairly soon after it begins to rain. Palmer [2], however, demonstrated conclusively that the spattering and transport of soil continues even after a water layer forms on the soil surface. According to him, soil losses due to splash erosion increase after a thin water layer forms on the soil surface and reach a peak when the thickness of the water layer is equal to the diameter of the drops, after which they gradually decrease.

Table 3

Amount of soil in Ellison pans on different parts of a slope

Number of observations	Mean, g	Mean error, g	Standard deviation	Coefficient of variation	Accuracy index	Reliability of sampling difference
Upper part of the slope						
15	150	3.70	14.3	9.5	2.46	
Middle of the slope						
15	146	4.16	16.1	11.0	2.85	1.56
Lower part of the slope						
15	141	4.44	17.2	12.2	3.14	

Our data also show that the action of the raindrops in detaching and transporting soil is observed to the fullest extent to a water depth of 4-5 mm. The splash distance then decreases and at 10-12 mm ceases altogether. Thus, after formation of surface runoff on a slope, splash erosion does not cease, as some investigators have assumed, but simply changes somewhat depending on the rainfall intensity and certain soil properties. It also varies widely according to the slope steepness and location of the plot on the slope in relation to the summit.

Studies of surface runoff have shown that its minimum depth is near the top of a slope. The water here flows in a more or less even layer. However, the surface layer here cannot be considered to be an even film. According to Grigor'yev flows of varying depth and velocity occur even at a distance of 2 m from the surface of the sprinkling boundary. Downslope the amount of water increases gradually due to the water coming from above. At the same time the concentration of flows also increases. Most of the water rolls down over several microdepressions in which wide but' still not very deep flows occur. Downslope they merge to form wide deep streams capable of transporting a large amount of water. The space between streams is covered with a thin layer of water, which flows in the direction of the main slope and toward the nearby troughs. The depth of runoff here is small and generally does not exceed the critical values at which the eroding action of the raindrops ceases. Thus, even after the formation of surface runoff from most of the slope, the action of the raindrops in separating and transporting soil is fully preserved. This can be judged from the presence of soil in Ellison pans (Table 3), which are arranged in such a way that soil can only fall into them from the air with the splash-back of particles. However, with the occurrence of surface runoff, the nature of the separation and, especially, the transport of soil particles changes somewhat, with a shallow water depth (10-12 ram) the drops, as happens before there is surface runoff, break up the soil aggregates and transport them down the slope. The eroding action of the raindrops and the splash distance decrease somewhat, but the amount of soil transported does not decrease significantly because excessively wet soil is more readily separated. Splash-back entraps and transports not only parts of the aggregates but also the suspended soil particles. The rate of transport does not decrease either, despite the slight decrease in the splash distance of the drops, because the soil raised by raindrops is not simply displaced but also may be transported in the moving flow to a much greater distance than it could have splashed. With a deeper water layer (12-15 mm) the raindrops do not reach the soil directly but, on striking the water surface, create a shock wave, which in turn acts on the soil by stirring up the small particles.

With increasing distance from the summit, the surface runoff becomes increasingly saturated with soil separated by the raindrops. Its separating and transporting capacity increases with increasing concentration [4, 5]. However, at some point the concentration of runoff reaches its maximum carrying capacity. The flow rate slows, and some of the transported soil begins to be deposited.

Table 4

Runoff and soil loss on plots of different length

Plot length, m	Liquid runoff, m3/ha				Solid runoff,			
	first year	second year	third year	mean	first year	second year	third year	mean
8	2840	1857	4589	3095,3	7,98	6,99	29,34	14,77
16	2265	1860	4007	2710,7	7,33	4,09	17,60	9,67
24	2904	1755	4045	2901,3	11,77	3,62	16,91	10,77
32	3557	2463	5027	3682,3	13,88	5,71	24,59	14,23

In doing so the zone of "pure" erosion is replaced by a transit zone within which there is an approximate balance between soil loss and deposition of erosion products transported from above. The width of this zone depends on slope steepness, depth of flow, etc. As the runoff moves along and becomes saturated with soil, it loses the properties of a flowing liquid and is transformed, as it were, into a mud flow sliding slowly down the main slope and in the direction of the nearest trough. The deposition of soil prevails here over soil loss; hence, the transit zone gives way to a zone of accumulation. Nearer the base, as the angle of surface slope decreases, the flowing mud comes to a complete stop. It is natural that with such a method of soil separation and transport the upper parts of the slopes near the summits become more eroded.

In troughs the soil creeping down adjacent slopes and detached directly in channels is picked up by thick flows and transported beyond the slope.

The results of research show that in the humid tropics of Cuba soil erosion by water is due not only to surface runoff, as in temperate regions [3]. It is a process of soil separation and transport by raindrops and surface runoff. The soil is separated mainly by raindrops and transported both by the raindrops and by surface runoff. Most of the soil detached is not transported beyond the slope but migrates from the summit to the base of the slope.

The intensity of rainfall erosion in Cuba depends to a large extent on slope steepness and form. To study this relationship, we selected plots on slopes of varying steepness but with the same agricultural use. Profiles were taken on these plots in which the thickness of the rest of the genetic horizons and profile as a whole was measured. The results show that the intensity of erosion is directly proportional to slope steepness and is described by the equation $y = 51.43—2.35x$ where y is the thickness of the humus layer (A+B) in cm and x is the slope steepness in degrees.

The effect of slope length was studied on runoff plots in the province of Pinar del Rio. The results are so inconsistent that they neither confirm nor deny the effect of slope length (Table 4). In some cases there is a limited increase in soil loss on the long plots and, in others, on the shorter plots.

Such a wide variation in soil loss and the absence of a relationship between soil loss and length of runoff plots are due most likely to the presence or absence of organized water flows within a given plot. With a stream on the plot, runoff increases with increasing plot length. Where there is no running water, splash erosion with all its characteristics is dominant. Thus, scarcely any soil loss occurs beyond the plot. Accordingly, we attempted to evaluate the effect of slope length on erosion by comparing their actual erodibility. In Cuba, however, it is practically impossible to find slopes of different length with the same steepness. Generally, the longer the slope the less steep it is. We therefore studied the thickness of soil and the erodibility of the same straight slope at different distances from the summit. To estimate the amount of soil lost from a slope, we used the method of gully measurement and found that in the tropics as well as in temperate regions gullies enlarge with increasing distance from the summit in accordance with the patterns of rainfall redistribution by the terrain.

Table 5

Size of gullies and thickness of a Cinnamon-Brown Calcareous soil profile on different parts of a slope

Part of the slope	Slope steepness, deg	Profile thickn., cm	Size of gullies, m3/ha			
			mean	standard deviation	mean error	coef. of variation
Crest	1	12	0,5	0,08	0,03	16
Upper third	7	25	2,5	0,38	0,17	15
Middle third	18	54	5,1	0,82	0,37	16
Lower third	12	73	13,4	2,41	1,03	18
Base	2	85	4,3	0,55	0,24	13

Thus, if soil erosion were determined only by running water, we would find the lower part of the slope to be the most eroded. Actually, however, the thickness of soil on the slope increases from the summit to the base, i.e., in the same direction in which the size of the gullies increases (Table 5).

This inconsistency suggests that the soil detached in the course of sheet erosion is transported in two ways: in suspension or by movement in flow concentrations in troughs and in the form of a mud flow creeping down the slope in spaces between the troughs. Much more of the erosion products is transported by the second process. They overcompensate for the soil loss by concentrated flows from the lower parts of the slopes and help to increase here the thickness of the soil profile. This makes it extremely difficult to evaluate the effect of slope length on erosion. The method of runoff plots used for this purpose ana, especially, the method of gully measurement are clearly unsuitable because the results are understated.

To study the effect of slope profile and form on soil erosion, the method of soil geomorphologic profiles was also used. A series of profiles was taken on a given slope form from the summit to the base of the slope. The thickness of genetic horizons and its profile as a whole were measured in each of them. It was found that on straight slopes the upper parts are most eroded. A similar picture is observed on concave slopes. Convex slopes are eroded somewhat differently. On gentle slopes the upper parts are more severely eroded but on slopes of 10-15° or more the more convex parts are the most eroded. There is probably a critical break angle in the surface where the soil loss from the steepest part increases to such an extent that it cannot be compensated by soil from above.

Not only the profile of a slope but its form exerts an unusual effect on sheet erosion. On so-called waxing slopes, the upper parts are the most eroded, while in troughs made by runoff and on adjacent slopes there is a large accumulation of erosion products. On waning slopes, the upper parts are also heavily eroded but the zone of accumulation here is wider and therefore not as pronounced.

In Cuba, especially in regions where karst phenomena are common, there are complex slopes on the surface of which are microelevations or depressions. In this case these microelevations, regardless of their position on the slope, are the most eroded. The severe erodibility of microelevations on slopes is due to the fact that the soil mass creeping down the main slope flows, as it were, around them and so the soil transported from them is not compensated for. In this case they appear as independent elevations whose base is the main slope. Soil eroded from such microelevations does not accumulate at the base but creeps down the main slope. An exception is the microslope directed upward in relation to the main slope. Here, at the junction of the microslope and main slope, accumulates soil eroded from the microelevation and part of the soil which has crept down the main slope but which is retained by the microelevation.

Our studies have shown that the process of rapid soil erosion by water in the humid tropics is significantly different from that in temperate regions and requires a radical reexamination of the principles of soil protection against erosion in Cuba.

The soil-conserving system here should have two sets of measures. One should provide for the protection of soils against the eroding action of raindrops while the other should be aimed at regulating the surface runoff. The second set of measures can only be effective when applied in conjunction with the first. The use of both of these sets of erosion-control measures should be differentiated. In some cases it will suffice to protect the soil against erosion during periods of rainfall by means of a basic, catch, or cover crop. In other cases it will be necessary also to design a system of soil cultivation based on erosion control and the implementation of some special measures directed at regulating surface runoff.

Received May 13, 1987

BIBLIOGRAPHY

1. GRIGOR'YEV, V. Ya. 1984. Forecast of erosion after sprinkler irrigation and justification of some erosion-control measures. In: Aktual'nyye voprosy ero- ziovedeniya (Current problems of erosion science). Moscow, Kolos.

2. GERRARD, A. J. 1984. Pochvy i formy rel'yefa (Soils and landforms). Leningrad, Nedra (Translated from the English).

3. ZASLAVSKIY, M. N. 1979. Eroziya pochv (Soil erosion). Moscow, Nauka.

4. MAKKAVEYEV, N. I. 1955. Ruslo reki i eroziya v yeye basseyne (River bed and erosion in a river basin). Moscow, Izd-vo AN SSSR.

5. MAKKAVEYEV, N. I. 1984. General patterns of erosion and river bed processes. In: Erozionnyye protsessy (Erosion processes). Moscow, Mysl'.

6. MIRTSKHULAVA, P. Ye. 1970. Inzhenernyye metody rascheta i prognoza vodnoy erozii (Engineering methods of calculating and predicting water erosion). Moscow, Kolos.

7. S0B0LEV, S. S. 1948. Razvitiye erozionnykh protsessov na territorii Yevropey- skoy chasti SSSR i bor'ba s nimi (Development of erosion processes in the European USSR and erosion-control methods). Moscow, Izd-vo AN SSSR.

8. SHVEBS, G. I. 1974. Formirovaniye vodnoy erozii, stoka nanosov i ikh otsenka (Water erosion and alluvium runoff: an assessment). Leningrad, Gidrometeoiz- dat.

9. ELLISON, W. D. 1952. Raindrop energy and soil erosion. Empire J. Experim. Agric., 20, No. 78.

10. MITCHEL, KENT. 1983. Mechanisms of soil erosion. World farming, 25, No. 1.