Soil Erosion by Rainstorms

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WHEN A VIOLENT RAINSTORM strikes a bare field there are two erosive agents at work—the falling raindrops and the flowing surface water. Each works through a different erosion process, and each forms different products.

The basic erosion process is one of detaching and transporting soil materials. Falling raindrops accomplish this through splashing particles of soil into the air (splash erosion). The runoff erodes by a scouring action as it flows downslope (scour erosion). In the splash erosion process the energy of the raindrops is applied uniformly across whole fields, whereas in scour erosion the energy of the runoff concentrates along narrow lines of flow.

The effects of these two erosion processes are very different. The raindrops erode thin layers of soil over broad reaches of hillsides, whereas erosion by surface flow tends to carve rills and gullies along the lines where runoff concentrates.

On smooth and level field surfaces, the splash process merely "kicks" particles of soil back and forth, without causing a net loss from any point. But on a hillside, the splashed soil creeps downslope. Measurements have shown that a violent rainstorm may have a splash capacity of more than 100 tons per acre. Still other measurements have shown that on a 10 percent slope this downgrade transportation of splashed soil is about three times the upgrade. The downslope movement may be observed whenever a rainstorm beats down and flattens a small pile of sand in an open yard. There is seldom any surface flow down the sides of the pile, and all of the sand must be transported by the splashes of the falling raindrops. (See Fig. 1.)

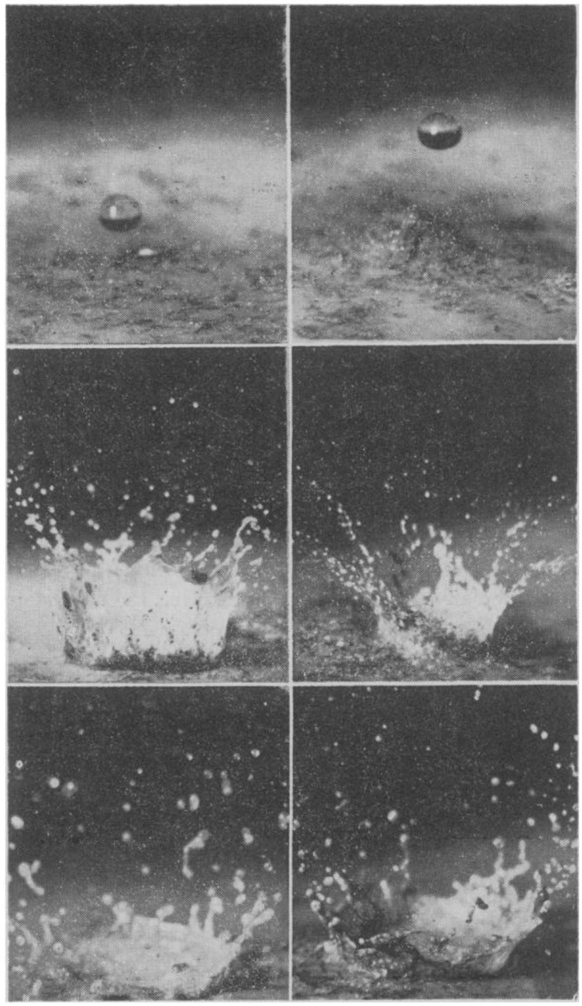

FIG. 1. Splash erosion. *Left*: top—a falling raindrop approaches a soil having a thin film of water covering; middle—the splash reaction throws soil and water into the air; bottom—the cavity lends proof of the effects of splash erosion on the soil. *Right*: top—a falling raindrop approaches a wet soil; middle—there is not enough water to raise a continuous film as in the photograph at the left; bottom—the cavity indicates that the soil has been moved downslope and what remains is puddled and damaged in other ways. Photographs show actual size. They were made by Naval Research Laboratory, Washington, D. C. V. P. Robey, photographer.

Splash erosion moves soil down field slopes in about the same way that it moves sand down from the top of a pile. However, under most field conditions, its action is accelerated by runoff. Each time splashed particles fall back into the runoff they may be floated, dragged, or rolled some distance downslope before being deposited or coming to rest on the surface. If velocities are low, and if most of the soil particles are large and heavy, the runoff may float out only the organic matter, clay fractions, and other fine and light materials.

The scour erosion process acts very differently. It is limited in the main to narrow flow lines and, contrary to general belief, it does not usually cause sheet erosion, except as it is assisted by what we shall term a feeder agent. This feeder agent detaches particles from smooth field surfaces outside the rills and gullies and moves them into the lines of concentrated flow. On cropped fields the splashing raindrops and many of the ordinary tillage implements serve as feeders, moving surface soil into the flow lines and thus producing sheet erosion. But on lands that are permanently in good grass covers, these feeder agents are not active. Here erosion is limited to gullies, and sheet erosion effects do not appear.

So long as man has tilled the soil he has had a constant struggle to maintain his lands against damages by soil erosion. Unfortunately, this struggle has been made more difficult through his failure to recognize the splash erosion process. Until very recently, this process represented an important missing link in soil erosion science. Efforts to check soil erosion were based almost entirely on controlling surface flow with terraces, contour ridge rows, and other types of contour impediments which retard velocities of runoff and thereby curtail the erosive capacities of flowing surface water. Such practices tend to prevent gullying, and to reduce the downhill transportation of splashed soil particles that fall back into the runoff. But they are not effective in preventing the downslope creep of soil in splash erosion processes.

A study of both ancient and modern soil conservation undertakings discloses failures which probably should be charged to uncontrolled splash erosion. Some of these failures occurred even though surface flow seems to have been effectively reduced. One example was reported by Lowdermilk (*7*). Following an inspection of lands about the city of Jerash (formerly called Gerasa), located on the Chrysorrhoas, which leads into the Zerka, in the valley of the Jordan, he reported in 1939 that he found soils washed off to bedrock, in spite of rock-walled terraces.

A development similar to that reported by Lowdermilk, but on lands protected with modern terraces, was reported by Cox (*2*), from Guthrie, Oklahoma. Following a checkup on an experimental field that had been terraced, he stated that over the last eight years it had lost from 6 to 8 inches of soil. (See Fig. 2.)

To control splash erosion we must break the fall velocities of raindrops before they strike the ground. This may be done with mulches of straw or leaves, or with dense growths of vegetal covers on the ground. Even before the splash erosion process was recognized and explored experimentally, vegetal covers were

FIG. 2. Terraced field at Guthrie, Oklahoma. Soil Conservation Service photo.

known to have some beneficial effects in conserving soil and water. Plato must have had some of these benefits in mind when, according to Toynbee (*9*), he wrote of Attica:

> Contemporary Attica may accurately be described as a mere relic of the original country, as I shall proceed to explain. . . . All of the rich, soft soil has moulted away, leaving a country of skin and bones. . . . There were also many lofty cultivated trees, while the country produced boundless pastures for cattle. The annual supply of rainfall was not lost, as it is at present, through being allowed to flow over the denuded surface into the sea, but was received by the country, in all its abundance, into her bosom, where she stored it in her impervious potter's earth and so was able to discharge the drainage of the heights into the hollows in the form of springs and rivers with an abundant volume and a wide territorial distribution.

In 1877, Wollny (*10*), a German scientist, wrote about the effects of a beating rain in breaking down the soil structure, and the protective effects of a vegetal cover in reducing these damages.

Some of the present-day experiments that stand out as classics in this field were conducted by Laws (*6*). and Borst and Woodburn (*1*). In both studies the effects of variations in raindrop impacts on the amounts of soils carried in the runoff waters were measured. Results showed conclusively that increases in drop impacts tended to increase the amounts of soils carried by the runoff. However, these experimenters apparently did not recognize splash erosion as an important independent erosion process.

The first known reports on splash erosion were made by the writer (*3, 4, 5*). Techniques entirely new to the field of soil erosion were developed for studying the splashed soil. Sreenivas (*8*) later used these techniques to measure the protection afforded soils by different kinds and amounts of vegetal covers. Woodburn (*11*) also employed them to determine the detachability of different soils when exposed to raindrop action. Work along these lines has progressed so as to permit fairly exact determination of the amount of vegetal cover required to preserve each different soil, and the protective values of different kinds and amounts of mulches and growing vegetations can also be measured. These developments now enable us to match each different soil with a cover tailor-made to its protective requirements.

Results of Soil Erosion

Splash and scour erosion processes damage the land in at least four important ways. They carve gullies, they remove sheets of surface soil, they remove organic matter and other soil nutrients even without significant net loss of soil from the surface of the land, and they puddle soils, making them droughty and reducing productivity.

"Gully erosion" and "sheet erosion" are commonly accepted terms. But we need another term, "puddle erosion," to distinguish between puddling caused by erosion and that caused by other agents. Also, we need the term "fertility erosion," to denote the removal of a soil's fertility elements by an erosive agent. These terms will clarify some of our problems in erosion control. Many smooth and level lands do not need protection against gully or sheet erosion but do require control measures to check puddle or fertility erosion—that is, the soil needs a cover to protect it from raindrop impact.

Puddle erosion. Raindrops, working through the splash process, cause most of the damage in puddle erosion. They break down clods and crumbs of soil and compact these broken materials. The inflow of surface water made muddy by splash further seals surface cracks and pores and tends to "waterproof" the land.

The first step in the control of damage by soil puddling is to control splash erosion. Some recent tests on open ranges disclosed that overgrazing, which removed too much of the grass, permitted excessive splash erosion to make the land almost waterproof. These tests showed that with a good grass cover, containing about 3 tons of forage and litter per acre, only about half a ton of soil per acre was splashed, and the water intake was 2.36 inches during a 15-minute period.

On other areas, where there was less forage and litter cover, the splash erosion tended to increase, and the water intake to decrease, with each reduction in the vegetal materials. Finally, on bare areas where there was no cover at all, 70 tons of soil was splashed on each acre, and water intake was reduced to 0.10 inch in 15 minutes.

These reductions in water intake can be charged in the main to surface sealing. But splashing raindrops may puddle and seal deep sections of the profile, as well as the surface, on many soil types. Turbid water, charged with colloidal materials, sometimes enters the soil through large surface openings. Upon reaching the bottoms of such openings these materials are deposited to form a dense and highly impermeable core. It is my belief that these actions have a hardening effect which makes many soils less pervious, decreases intake of rainfall, curtails yields to ground water, and increases runoff. This imperviousness develops at different rates on different soils. Exploratory examinations of several field situations has indicated that it may take from 25 to 1000 years of farming (with uncontrolled splash erosion) for this deep sealing to develop an important effect on some of the different soils. (See Fig. 3.)

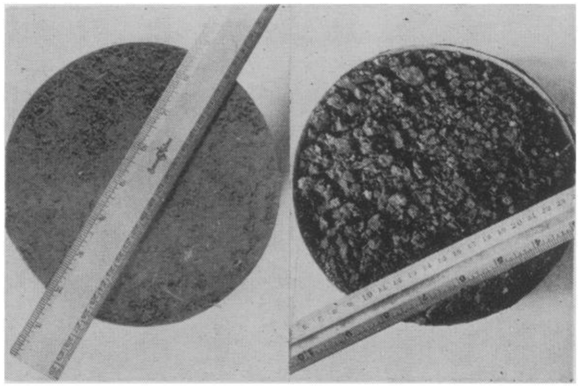

FIG. 3. Puddle erosion hardens the land so that water does not enter freely. Soil at the left has been subject to puddle erosion; that at the right has not. Soil Conservation Service photo.

There are indications that erosion control practices made top-heavy with contouring operations, where splash erosion continues uncontrolled, may aggravate this deep sealing and hasten the land-hardening process on many soil types. On these soils, practices that are employed for water conservation and flood control will in the long run defeat the very purposes for which they are intended.

Fertility erosion. The effects of fertility erosion may be seen on level fields of bare sandy soils, after a heavy rain. (See Fig. 4.) They are about the same as would be produced by washing a thin layer of surface soil in a washing machine—there is little more than coarse sand left.

Out on open fields the churning action of splashing raindrops breaks down clods and crumbs of soil and releases chemicals, organic matter, and clay fractions into the surface water. The runoff, made turbulent by the splashes, may carry considerable amounts of these important parts of the soil off the fields.

The fertility erosion process, which removes only the lighter elements from the heavy sands, can be more

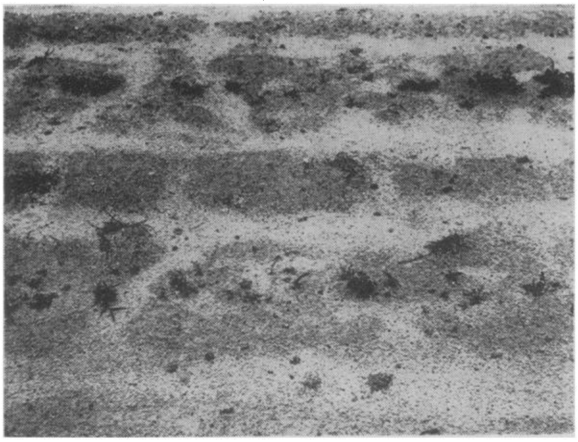

FIG. 4. Fertility erosion is an important process in making deserts. It removes the soil's fertility elements and destroys the land's water-holding capacity. Soil Conservation Service photo.

injurious to sandy lands than sheet erosion, which removes the whole soil. Some fields have been damaged to an extent that the plow layer is composed almost wholly of coarse sand. This material has lost not only fertility, but also a considerable part of its water-holding capacity. During hot summer weather it may become droughty within a few days after a heavy rainstorm.

Many efforts have been made to build up the organic matter of these soils. Using organic matter in this way while fertility erosion remains uncontrolled is a wasteful practice. Proper erosion control would prevent the loss in the first place.

Sheet erosion. The effects of sheet erosion are widely recognized. (See Fig. 5.) They usually appear first near the tops of slopes, where subsoil may be exposed across broad reaches. From here they are extended downslope by rainstorms.

FIG. 5. Sheet erosion. Falling raindrops splash the soil down from tops of slopes, tending to flatten them, just as they flatten ~~sandpiles in~~ open yards. Soil Conservation Service photo.

The difference between the processes that cause sheet erosion and those that cause fertility erosion depends largely on soil transportation. Where the transportation is insufficient to remove all of the soil particles that are detached and set in motion by the splash, only the lighter materials may be lost from the eroded area and the result will be fertility erosion. But where the erosive agents have sufficient transporting capacity to keep the whole soil in motion downslope, the result will be sheet erosion. Several important factors control the transportation phase of erosion processes. These include the slope of the land, the transportability of the soil, the transporting capacity of the erosive agents and the surface conditions over which the water flows.

The effects of sheet erosion are most injurious to lands having a thin layer of surface soil underlain

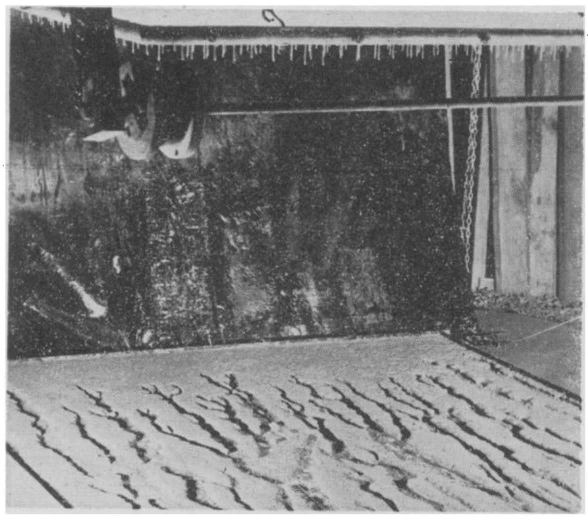

FIG. 6. Gully erosion is a product of the scour process. On this small plot the rainmaker was lowered to the surface and drops were released without impact. The soil was only about one inch deep, so that some of the washes spread in width more than they would have in deeper soil. If the raindrops had been applied with impact they would have served as a feeder agent and all of the soil would have been washed away. Soil Conservation Service photo.

with hard rock. On these the loss of only a shallow depth of soil will completely destroy productivity. Sheet erosion is least injurious to lands where there is little difference in the productive capacities of the surface soils and their subsoils, particularly if the subsoils are deep and of a quality that is easily made productive.

Gully erosion. Flowing surface water is the controlling erosive agent in carving gullies. (See Fig. 6.) However, splashing raindrops may contribute to the process, in at least two ways: through puddling the land surface and thereby increasing the amounts of runoff available to do the gully carving, and through splashing abrasive soil materials into suspension.

Flowing surface water working through the scour process was the principal erosive agent active in carving the Grand Canyon, the river systems, and myriads of small valleys. The erosion that carved the important drainage systems must be classed as beneficial to the land. But aside from creating channels needed for drainage purposes, gullying is usually a very destructive process. A gully often dissects sloping lands to the extent of making them unworkable or even impassable.

Gully-filling projects have been widely publicized during the past two years and this work has been hailed as giving new birth to farm lands. Its value should not be underestimated, but such operations only repair damages to the terrain, they do not reestablish the lost soils. Since these repairs usually make tillable badly depleted soils that are highly susceptible to erosion, it is essential to check splashing raindrops as well. The usual contouring operations which control the scour process may eliminate gullying, and to a limited extent reduce rates of sheet erosion. But they do not fully check sheet erosion processes, nor do they protect soils against the damage of fertility and puddle erosion. Because of this oversight, many of the gully-filling projects now in progress will exploit the soil rather than conserve it.

History records many great conservation movements, most of which have failed in the long run. Recent splash erosion studies reveal a plausible explanation for some of these failures. The conservationists did only part of the job. They recognized and controlled the scour erosion process caused by the runoff, but failed to reckon with the most destructive process of all—splash erosion. Even today we rely entirely too much on contouring operations and we take too much pride in the beauty of fields whose rows bend with the contours, but where bare soil between these rows betrays careless soil and water management practices.

Farmers and ranchers have long known that cover was beneficial in conserving soil and water. But the specific protective values of different covers and the protective requirements of different soils were unknown. About the only cover evaluations made in the past related to the effects of cover on reducing soil loss. Such experiments do not apply to flat lands, where soil loss is often unimportant. Even on rolling lands they have limited application. For example, an area may be well protected with a crop cover, so that there will be no puddle, fertility, or sheet erosion damages. Yet a single gully may cause great soil loss. In contrast to this situation, other fields may have very little cover protection, resulting in high puddle, fertility, and sheet erosion damages but no important soil tonnage losses from the land. It is wrong to assume that soil loss measured in the runoff water is always proportional to erosional damage on these fields. Soil loss carried in the runoff actually bears no fixed relationship to puddle, fertility, and sheet erosion damage. It is, however, a fairly sensitive measure of the damage caused by scour erosion as it carves gullies. Because of this, our present-day conservation practices are very effective for scour erosion control purposes, but they are not fully adequate for purposes of controlling the splash erosion process.

The effects of processes that are inconspicuous and seldom seen are apt to be underestimated. For more than five thousand years we have concentrated our research efforts on the erosion caused by runoff, while neglecting to develop a physical science for an attack on the problems of erosion by raindrops. But it is the raindrops we must control first of all to achieve effective and lasting results in protecting the land.

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