There is a dark side to the humble raindrop

A single drop is harmless, but when billions of raindrops fall from a cloudburst onto bare soil they strike like billions of tiny hammers, dislodging tons of soil per acre which is carried away by surface runoff.

This process, called splash erosion, is of critical importance to agriculture. It is the initial stage of water erosion, which causes an estimated $27 billion in on-site economic losses in the United States annually. In addition, rain splash has played a major role over geologic time in sculpting the features of the mountains and cliffs of the world, particularly those in arid and semi-arid regions.

Despite its importance, there is a lack of understanding of the fundamental processes involved in this natural phenomenon that makes it difficult for researchers to assess the reliability of the experimental data that exists. This lack is addressed by the first study to use a high-speed camera to analyze the interaction between individual rain drops and soil particles, published on Jan. 16 in the *Journal of Geophysical Research*.

In the new study researchers from Vanderbilt and Arizona State University have dispelled a 50-year-old misconception about how rain-splash transport works and have produced a theoretical model for the way in which the momentum carried by raindrops is transferred to the sand grains that are blasted away from the impact site. (Individual raindrops, which travel at speeds up to 20 miles per hour, can splash soil particles up to five feet horizontally and two feet into the air.)

When the model is used with new sources of information like Doppler radar, which can provide data on average raindrop size and velocity in actual rainstorms, it could provide more reliable estimates of the amount of splash erosion taking place in different environments.

"The more we understand the basic physics of the splash erosion process, the better we can become at controlling it in the farmer's field," says David Furbish, professor of earth and environmental sciences at Vanderbilt, who directed the study. His collaborators were Mark Schmeeckle, assistant professor of geography at Arizona State University, Vanderbilt Research Associate Simon Mudd, and Vanderbilt students Katherine Hamner and Miriam Borosund, now at Dartmouth College.

The experiments consisted of mounting a 20-foot PVC pipe vertically and attaching a syringe at the top of the pipe. The distance was great enough so that the raindrops nearly reached terminal velocity, the fastest speed that they can travel through still air. The pipe prevented errant air currents from deflecting the drops. A sand target, which was two centimeters deep and 2.5 centimeters in diameter, was set flush to a surrounding surface that is covered with sticky paper. The syringe produced individual water drops of different sizes. When a drop hit the target, a high-speed camera, operating at 500 frames per second, recorded the dynamic interactions between the water and the sand. The grains ejected by each impact stuck to the surrounding paper where they hit, allowing the researchers to plot their positions precisely.

The researchers investigated the impacts of raindrops of three sizes: two, three and four millimeters in diameter. Natural raindrops come in sizes up to 6 millimeters. The water drops were dropped onto three grades of quartz sand: fine, medium and coarse with grain sizes of 0.18, 0.35 and 0.84 millimeters, respectively. The experiment also investigated the effect of slope by setting the target at six inclinations (0, 10, 15, 20, 25 and 30 degrees).

The high-speed camera revealed that when small drops fell onto coarse sand, they hit without a splash and disappeared with scarcely a trace. But when a large drop falls onto fine sand, it flattens out and pushes a ridge of grains ahead of it. At about the same time that it blasts the sand grains into the air, the drop begins to contract, pulled back by its own surface tension, leaving behind a small impact crater.

The difference in the impact of different size raindrops didn't come as a surprise. The energy in raindrops increases dramatically as they get bigger. For one thing, they weigh more. The mass of a five millimeter raindrop is 125 times greater than that of a one millimeter drop. In addition, larger drops travel faster. The terminal velocity of a five millimeter drop is twice that of a one millimeter drop. As a result, a five millimeter drop has 250 times the destructive energy of the one millimeter drop.

When they began tilting the target to see what happens on sloping surfaces, however, they did discover something they didn't expect. For more than 50 years, scientists have known that soil particles detached by rain splashes move down slope farther than they move sideways or upslope. The generally accepted explanation has been that this is caused by the fact that particles ejected down slope travel farther before coming to rest than those ejected in other directions. The experiment confirmed this effect but found that there was a second, unexpected contribution: More grains are ejected in the down-slope direction than in other directions, and they are ejected at higher velocities. This is particularly important because splash erosion does the most damage on sloping surfaces. Impacts on inclined surfaces also replicate those of wind-driven drops.

"By providing a clearer explanation for this phenomenon, our study will inform further studies aimed at relating transport rate to sediment size and drop intensity," says Furbish.

Scientific efforts to understand and predict soil erosion date back to the "dust bowl" days of the Great Depression in the 1930's. The U.S. Department of Agriculture began an effort that resulted in the Universal Soil Loss Equation. This is a purely empirical formula designed to relate agricultural practices to soil erosion.

"The Universal Soil Loss Equation was created by using a large sledge hammer, namely going out, measuring soil properties, estimating rain properties, looking and categorizing land use practices, putting in erosion pans and gutters to catch sediment in order to measure the amount of erosion, plotting the data, analyzing it statically to come up with a formula that could be handed back to the farmer," says Furbish. "Here's the problem: This formula was created from a finite data set pertaining to a finite range of slopes, a finite range of soil properties, a finite range of rain properties, and so on. It has since been applied universally, which means that under many circumstances it has performed poorly because it is being applied to conditions beyond those for which it was developed.

"The aim of research like ours is to produce a theoretical foundation for describing these processes that can be used to model landscape evolution as well as improve upon the Universal Soil Loss Equation," Furbish says.

Source: Vanderbilt University