1576-A

Soil detachment and aggregate disintegration by wind-driven rain

Leon Lyles

Rainfall's ability to cause soil erosion is closely related to its kinetic energy (*25*). Energy values have been used to estimate soil erosion and to relate simulated with natural rainfall. Although many rainfall events are accompanied by strong winds, only limited knowledge has accumulated on the effects of wind in increasing the rain's ability to cause soil detachment and aggregate (clod) disintegration. The wind's effect is not generally considered in rainfall-erosion studies; suggested amounts of protective mulches are based on no-wind or average wind conditions for data from long-time rainfall-runoff plots.

Research has shown that waterdrops falling in wind tend to be oblate spheroids, with a flattened area between their bottom and upwind side (*12*).

Wind Effects on Raindrops

Wind affects the size of raindrops in a storm by limiting the upper size of drops, depending primarily on windspeed. Blanchard (*3*) found that drops smaller than 0.18 inch (4.6 mm) in diameter were quite stable. Disrud and associates (*11*) reported that 0.17-inch (4.3 mm) droplets were stable in size when windspeeds were below 20 miles per hour, but that drop breakup increased about 40 percent when windspeed reached 25 miles per hour. Umback (*22*), in a wind tunnel study, noted that 0.22-inch-diameter (5.5 mm) drops did not shatter after falling up to 12 feet in 13.6 mile-per-hour winds.

Caldwell and Elliott (*5*) concluded from a numerical investigation that raindrops falling through a logarithmic wind profile arrive at the surface retaining most of their horizontal speed. Consequently, the error should be small when a horizontal droplet speed equal to the mean windspeed is assumed at heights of 30 to 150 feet. Thus, the droplet energy is related to its vectorial velocity resulting from the vertical droplet velocity and the horizontal windspeed. For example, a 0.08-inch-diameter (2-mm) droplet in a 20 mile-per-hour wind has about 2.75 times more kinetic energy than the same droplet does in still air.

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Assuming horizontal wind, the angle of inclination of falling raindrops, θ (defined here as the degrees of deviation from the vertical), can be calculated from: $\theta = \tan^{-1} \bar{u}/v_t$; where $\bar{u}$ is horizontal mean windspeed at some reference height, and v_t is terminal droplet velocity. Ten of 33 storms (1963-64) at Urbana, Illinois, had angles of inclination of 55 degrees or larger (*19*). Van Heerden (*23*), citing Greyvenstein in South Africa, reported that 54 percent of the total quantity of rain from March 1959 to August 1962 fell in showers with angles of inclination larger than 25 degrees; 80 percent fell at angles larger than 15 degrees.

Winds Associated with Rains

To assess the wind's effect on raindrop energy, information is needed on the magnitude and probability of occurrence of winds associated with rains at various locations. Changnon and Jones (*7*) reported windspeeds during heavy rains from an 8- to 10-year study (Table 1). They also reported that during an average year in Illinois, rainfall will equal or exceed 0.5 inch during 7 hours. During 4 hours in such a rainfall wind gusts will exceed 25 miles per hour. Converting angle-of-inclination data to horizontal windspeed, the data (1963-64) of Rogers and associates (*19*) at Urbana, Illinois, indicated that 30 percent of the storms were accompanied by winds of 20 miles per hour or greater (assuming a median drop-diameter of 0.08 inch).

After processing 8 years of wind-rain data from four locations in Kansas, Disrud (*9*) concluded that winds accompanying rains are sufficient to significantly affect the rain's ability to cause soil erosion. For example, at Dodge City, 20 percent of winds occurring with rains in April have speeds of 22 miles per hour or greater (Table 2). A wind of 22 miles per hour at an elevation of 20 feet could increase the rain's kinetic energy 3.2 times over that in still air.

Table 1. Windspeeds during heavy rain hours at three locations (*7*).[a]

Location	Mean Hourly Sustained Windspeed	Mean Maximum Gust
	mph	
Springfield, Ill., 1956-63	12	36
Wilmington, N.C. (nonhurricane), 1954-63	13	37
Wilmington, N.C. (hurricane), 1954-63	39	77
Seattle, Wash., 1956-63	10	30

[a] Heavy rain hours defined as mean hourly intensities greater than 0.5 inch for Springfield and Wilmington and 0.15 inch for Seattle.

Table 2. Speeds of winds accompanying rain that are equaled or exceeded 20 percent of the time at locations in Kansas 1956-1964 (*9*).

	Windspeed (mph)			
Month	Topeka	Wichita	Dodge City	Goodland
March	17.9	19.9	19.6	18.0
April	21.2	20.6	22.2	19.5
May	19.5	18.7	19.3	20.5
June	18.2	18.4	17.4	17.2

Wind-rain data from other water-erosion-susceptible areas would be useful.

Soil Detachment by Wind-driven Rain

Many researchers have studied the role of raindrops in soil erosion, especially as raindrops influence soil detachment (*2*, *4*, *13*, *17*, *20*, *21*, and *26*). Although the mechanics of soil detachment are not well-understood, raindrop impact has been identified as a major force initiating soil detachment (*26*).

Because wind changes the angle of impact and adds a horizontal component to drop velocity (thus, increasing the kinetic energy of rainfall), soil detachment would logically increase in wind-driven rainstorms. Van Heerden (*23*) suggested that wind apparently does not account for soil movement (splash erosion), except as it changes rain's impact angle (kinetic energy of the rain).

Lyles and associates (*15*), from raintower-wind tunnel studies, found that at the same rainfall intensity, duration of exposure, and clod size up to 68 percent more soil was detached when windspeed was 30 miles per hour than when there was no wind (Table 3). Based on soil moisture data showing that clods can reach moisture contents above the liquid limit (Table 4), they also speculated that profile drag exerted by the wind on the clods could cause the saturated soil to flow through clod-support screens. In a more detailed study, Disrud and Krauss (*10*) concluded from covariance analyses that wind accompanying rain increased soil removal from clods by means other than changing droplet size or velocity. The wind-shear stress was about half as

Table 3. Effect of windspeed on average soil detachment from clods exposed for 30 minutes to three rainfall intensities (*15*).

Wind Velocity (mph)	Clod Size (in in diameter) 0.5 - 1.5, Rainfall Intensity (in/hr) 0.63	1.12	2.21	2.0 - 3.0, Rainfall Intensity (in/hr) 0.63	1.12	2.21
	% soil detached					
0	4	9	36	1	3	9
15	8	25	51	2	9	15
30	27	64	97	5	27	77

Table 4. Water content, on a weight basis, of clods after 10- and 30-minute exposures to three rainfall intensities (*15*).

Clod Size (in)	Air Dry	Liquid Limit	Duration of Exposure, Minutes: 10, Rainfall Intensity (in/hr) 0.63	1.12	2.21	30, Rainfall Intensity (in/hr) 0.63	1.12	2.21
	% moisture							
0.25 - 0.5	2.14	32.85	39.22	45.23	48.88	44.43	46.34	51.01
0.5 - 1.5	2.18	32.85	22.34	27.18	34.61	31.73	34.65	39.70
2.0 - 3.0	2.43	32.85	10.48	11.80	23.46	23.93	24.14	31.31

effective as rainfall kinetic energy in causing soil detachment.

Caldwell and Elliott (*6*) calculated that in the zone of steep wind-velocity gradient near the ground, raindrops can transmit part of their horizontal momentum to the air at some reference height. They reported possible stress increases (10 to 20 percent and greater) in the lowest 30 feet (10 m) under certain conditions (Figure 1).

Based on the cited studies, wind forces on the soil surface should be considered when estimating the soil-erosion potential of a wind-rainstorm.

Soil Physical Properties that Influence Disintegration

Researchers have identified several soil properties influencing erosion or erodibility, generally from regression analyses (*1*, *24*). No new important soil properties are expected to emerge as a result of wind accompanying rainfall events, especially as wind affects drop energy. But because of the added effect of profile wind drag, soil properties (or forces) that control water-absorption rate and magnitude, aggregate expansion on wetting, and cohesion may be more important to consider under wind than under no-wind conditions.

Lyles and associates (*15*) attributed small clods' (rather than large clods') greater susceptibility to disintegration by raindrop impact to faster clod saturation. For example, silt loam clods, 0.25 to 0.50 inch in diameter, reached moisture contents well above the liquid limit within 10 minutes after rainfall had begun (intensity of 0.63 inches per hour). Clods 2 to 3 inches in diameter had not reached the liquid limit within 30 minutes, when rainfall intensity was 2.21 inches per hour (Table 4).

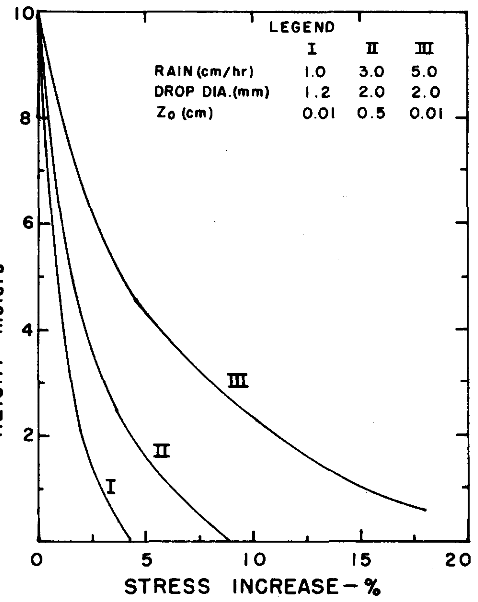

Figure 1. Percentage increase in the stress communicated by the air in the surface layer under various conditions. Z_0 is a surface roughness parameter. Mean windspeed at 10 meters is 500 cm/sec (6).

Lyles and associates (*16*) noted the marked resistance of equal weights (dry) of field-moist clods to breakdown by raindrop impact (0.28 pounds detached) as compared with that of air-dried clods (0.69 pounds detached) exposed to the same rainfall intensity and duration. Dry aggregates exhibit greater water-entry forces and degree of differential expansion on wetting than do moist aggregates. Unfortunately, field-moist clods lose their resistance to detachment long before they become air-dried (Figure 2). Consequently, there is little opportunity to use the resistance of moist clods in practical management applications. Air-dried clods are readily susceptible to breakdown by raindrop impact and wind drag because they rapidly absorb large amounts of water and expand, reducing corresponding shear strength to a low value.

Wind as a Factor in Control Methods

Many reports on soil erosion

have considered the effects of vegetation and vegetative mulches, which resist raindrop impact and flowing runoff (*8*, *14*, *18*, *21*). Although data obtained from natural rainfall-runoff plots may reflect wind effects on kinetic energy of natural rainfall, reports recommending amounts of protective mulches to control water erosion have generally ignored the influence of wind on raindrop energy and wet soil aggregates. Lyles and associates (*16*), however, found that when rainfall duration-intensity and clod size were similar for air-dried clods, rainfall detached about 2.7 times more soil when accompanied by a 25 mile per hour wind than when there was no wind, regardless of mulch cover present (Figure 3). When rain was driven by a 25 mile per hour wind, a 90 percent mulch cover was required to decrease soil detachment to amounts equal to that detached with about 12 percent mulch cover with no wind (Figure 3). They also found that when the amount of mulch was expressed in percentage of soil cover (rather than in the commonly used weight-per-unit area), soil detachment did not differ among mulches for winter wheat, grain sorghum, and corn.

Summary

Wind affects shape, size, energy, and inclination of raindrops. Limited

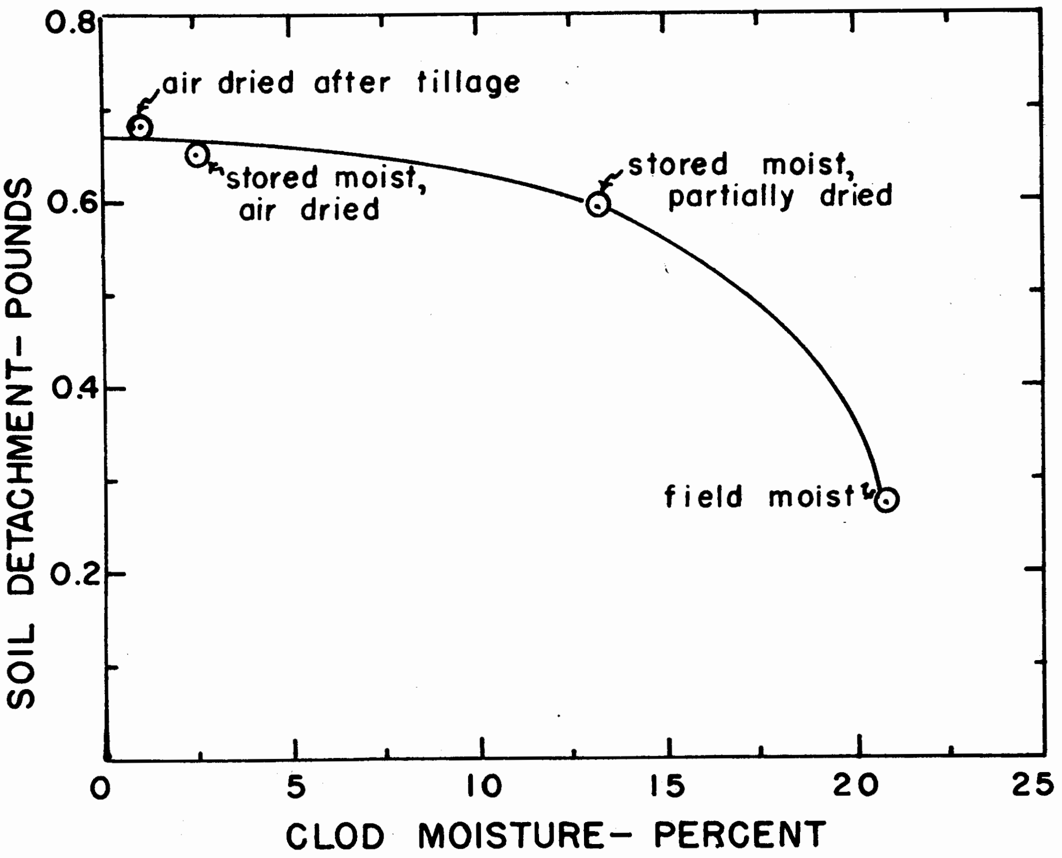

Figure 2. Effect of storage and drying on soil detachment by rainfall from clods 0.5 to 1.5 inches in diameter (16).

data indicates many rainstorms are accompanied by strong wind with two roles that increase rain's ability to cause soil detachment: by increasing drop vectorial velocity and, less known, by the profile wind drag's directly disintegrating wet soil aggregates. For example, wind-shear stress (drag) is about half as effective as rainfall kinetic energy in causing soil to detach from silt loam aggregates 0.5 to 1.5 inches in diameter.

When rainfall duration-intensity and clod size were similar for air-dry clods, rainfall detached about 2.7 times more soil when accompanied by a 25 mile per hour wind than it did in still air, regardless of percentage mulch cover. When rain was driven by a 25 mile per hour wind, a 90 percent mulch cover was required to decrease soil detachment to amounts equal to those detached in still air with about 12 percent mulch cover.

More research is needed on effects of wind-rain forces on soil-aggregate

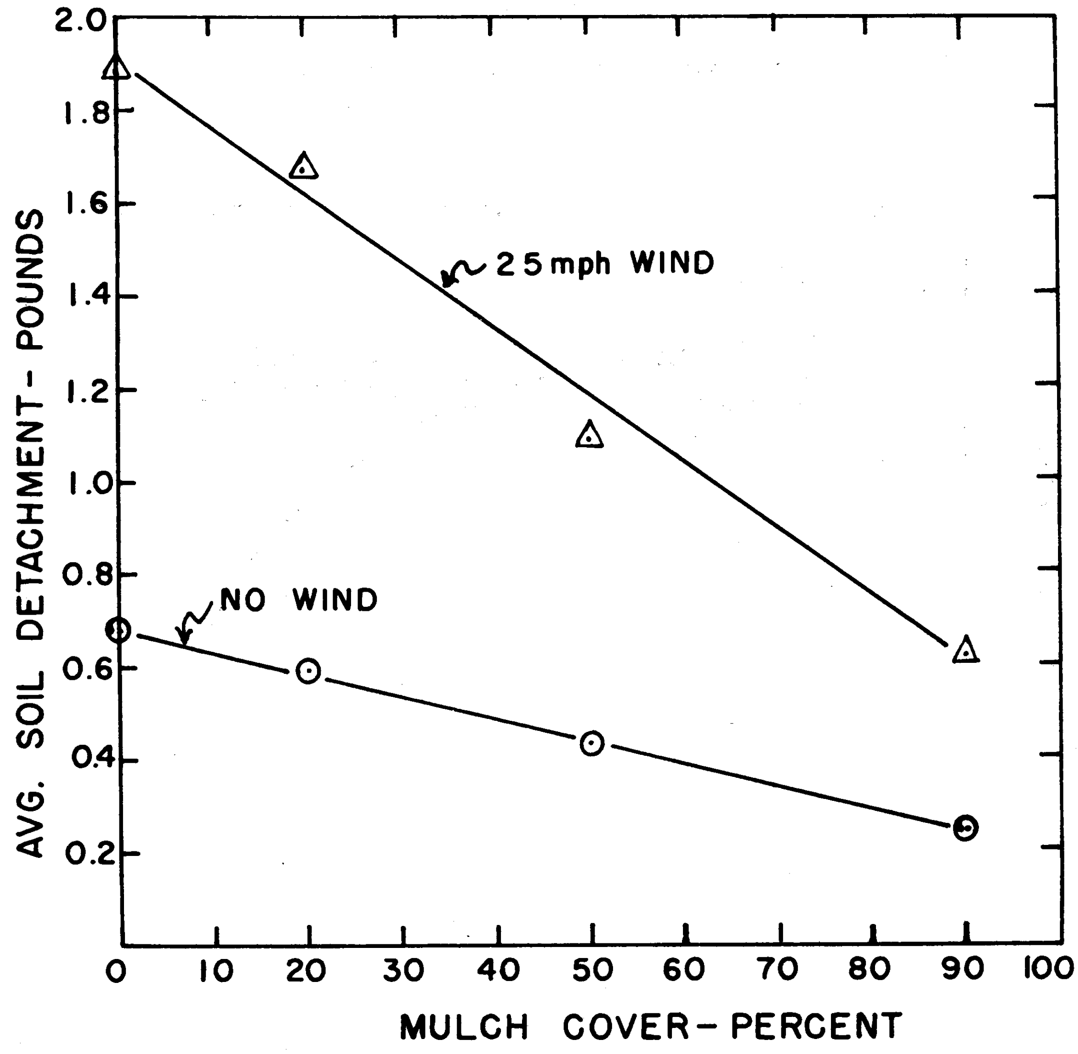

Figure 3. The effect of mulch cover and windspeed on soil detachment by rainfall from air-dried clods 0.5 to 1.5 inches in diameter (16).

breakdown over a range of soil texture and on the magnitude and frequency of winds associated with rains in areas susceptible to water erosion.

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