Soil Detachment from Clods by Rainfall: Effects of Wind, Mulch Cover, and Initial Soil Moisture

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ABSTRACT

When rainfall duration-intensity and clod size were similar for air-dried clods, rainfall detached 2.68 times more soil when accompanied by a 25-mph wind than when there was no wind. Consequently, the probability of wind accompanying rain is an important consideration in determining mulch-cover requirements to reduce soil detachment and subsequent sediment transport. When mulch cover and windspeed were similar, much less soil was detached from field-moist than from air-dry clods. Soil detachment from clods by rainfall did not differ among mulches of winter wheat, grain sorghum, and corn if the mulch quantity was expressed as percentage soil cover.

INTRODUCTION

A ROUGH, cloddy surface readily receives rainfall and is less wind erodible than noncloddy soils (Chepil 1957). Soil cloddiness, a transient condition, depends on many soil, climatic, and mechanical factors (refs. 2, 3, 12, 13), Clods formed by tillage are subsequently disintegrated by other mechanical manipulation and by climatic conditions. Research on the influence of clod size and density on soil detachment by rainfall for a silt loam soil has shown that wind-driven rain (common in Kansas) destroys more clods than do similar rains without wind (refs. 5, 6, 11).

Many reports on soil erosion consider the effects of vegetation and vegetative mulches, which resist raindrop impact and flowing runoff (refs. 4, 10, 14, 15, 16, 17). Few, if any, consider quantitatively the influence of wind on raindrop energy and wet soil aggregates. Suggested amounts of protective mulches to control water erosion are based on no-wind conditions.

This paper examines the combined effects of mulch kind and cover, initial soil-moisture content, and wind velocity on soil detachment from clods.

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TABLE 1. EXPERIMENTAL VARIABLES.

Variable	Symbol
Kind of mulch	
Winter wheat stubble	K_w
Grain sorghum stubble	K_s
Corn stubble	K_c
Percentage mulch cover	
0	C_0
20	C_{20}
50	C_{50}
90	C_{90}
Clod moisture	
1.03 percent (air-dry)	M_d
20.84 percent (field-moist)	M_w
Windspeed	
0 mph	$\bar{u}_0$
25 mph	$\bar{u}_{25}$

DESIGN AND DESCRIPTION OF EXPERIMENT

The experimental variables are summarized in Table 1. The study was a factorial experiment in a completely random design with three replications of each combination.

Table 2 gives certain physical properties of silty clay loam field clods formed by chisel tillage. Samples were collected, then sieved to obtain test clods 12.7 to 38.0 mm in diameter. After field-moist clods (M_w) were sieved, some were stored in airtight containers; others were air dried (M_d).

We placed 1500 g (3.307 lb) of clods (on an air-dry basis) on 38.1 by 45.7 cm trays of 2-mm screens, covered the clods with the appropriate kind and amount of mulch (Table 3), and exposed them for 45 min to a rainfall intensity of 1.76 in. per hr in a raintower wind-tunnel facility (Disrud et al. 1969 and Lyles et al. 1969). That rainfall intensity-duration is expected to occur about once every 2 years in central Kansas, but more frequently to the southeast and less frequently to the northwest (Yarnell 1935). Next, the clods, still in trays, were air dried (60 to 65 C) and reweighed to determine the quantity of soil material detached and passed through the screens. Mulches were oriented parallel with the wind for greatest effect and were anchored by a covering of wide-mesh netting.

Reference windspeed, measured with a pitot-static tube and associated recording equipment, was that in the center of the wind tunnel immediately upwind of the test samples.

TABLE 2. SOME PHYSICAL CHARACTERISTICS OF SOIL STUDIED.

Sand, percent	8.8
Silt, percent	60.0
Clay, percent	31.2
Bulk density before tillage, g/cm^3	1.48
Bulk density of test clods, g/cm^3	1.45
Soil moisture at time of tillage, percent*	22.85
1/3 bar, percent moisture*	25.15
15 bars, percent moisture*	10.64
Liquid limit, percent*	31.32

*Moisture contents on a weight basis.

EXPERIMENTAL DATA AND OBSERVATIONS

The average soil detachment in pounds at each level of the variables studied is presented in Table 4.

Table 5 summarizes the variance

TABLE 3. PHYSICAL DATA ON DRY MULCHES STUDIED; 12-in. LENGTHS CUT FROM SECTIONS NEAREST THE SOIL SURFACE.

Variable	Wheat	Sorghum	Corn
Diameter, cm	0.29 ± 0.04	1.96 ± 0.39	2.61 ± 0.46
Density, g/cm^3	0.16	0.12	0.15
Projected area per stalk, cm^2	8.93	59.80	79.64 (72.31)*

*Number in parenthesis is average per foot of lower 3 ft of corn stalks.

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TABLE 4. AVERAGE SOIL DETACHMENT AT EACH LEVEL OF THE VARIABLES STUDIED.

Clod moisture	Windspeed	Kind of mulch	Mulch cover, percent 0 (C_0)	20 (C_{20})	50 (C_{50})	90 (C_{90})
Percent	Mph		Soil detached, lb			
1.03 (M_d)	0 ($\bar{u}_0$)	Wheat (K_w)	0.74	0.60	0.42	0.29
		Sorghum (K_s)	0.68	0.63	0.44	0.22
		Corn (K_c)	0.64	0.55	0.45	0.22
	25 ($\bar{u}_{25}$)	Wheat	1.86	1.56	1.05	0.74
		Sorghum	1.86	1.74	1.16	0.53
		Corn	1.86	1.73	1.06	0.59
20.84 (M_w)	0	Wheat	0.21	0.20	0.15	0.10
		Sorghum	0.28	0.18	0.14	0.10
		Corn	0.34	0.18	0.17	0.08
	25	Wheat	0.46	0.37	0.27	0.16
		Sorghum	0.45	0.30	0.23	0.16
		Corn	0.47	0.30	0.20	0.15

ratios for the variables and their interactions. The significance of the interactions, especially higher order ones, restricts interpretation of the main variable effects. The kind of mulch did not significantly influence soil detachment (Table 6). Considerably less soil was detached from field-moist clods than from air-dried clods at similar levels of the other variables.

As expected, soil detachment decreased with increasing amounts of mulch cover and increased with windspeed (Table 7).

Multiple linear regression procedures were used to determine variance accounted for, and relative importance of "independent" variables (Table 8). A stepwise procedure was used with the variables entering in the order of greatest contribution to variance.

INTERPRETATIONS AND DISCUSSION

Parameters usually considered most important in evaluating vegetative mulches for soil and water conservation are (a) kind, (b) wieght per unit area, and (c) percentage of soil covered. Greb (1967) and Fryrear and Koshi (1971) reported that percentage of soil covered may be more appropriate to use in interpreting mulch effects on evaporation, soil temperature, and soil erosion than the more commonly used weight per unit area.

Because soil detachment from clods by rainfall and rainfall plus wind did not differ among kinds of mulch at the same percentage cover (Table 6), our results support those of Greb (1967) and Fryrear and Koshi (1971). However, to determine percentage of cover, some mulch measurements must be made in the field. The prevailing practice is to determine weight per unit area. Perhaps a more convenient way would be to relate potential cover to plant population (Fig. 1). Potential cover is defined as the percentage of the soil that would be covered if all stalks were dry, without leaves, and lying flat on the surface with no overlapping.

Average plant populations of grain sorghum and corn (which seldom exceed 30 percent soil cover) are considerably below the number needed for 100 percent potential cover. Consequently, reduced water erosion from the presence of corn or grain sorghum mulch would be attributed more to their effect on runoff than on soil detachment by raindrops (Kramer and Meyer 1969). Wheat populations and other closely drilled crops of similar stalk diameter and density generally could provide 100 percent potential soil cover; thus, they would offer greater protection to soil aggregates than does grain sorghum or corn.

Except for the first increment of cover for field-moist clods, the soil detachment decreased linearly with increasing cover. However, 100 percent cover alone apparently does not reduce soil detachment to zero, probably because stalk overlapping increases as percentage of cover increases and because some soil is removed by water draining over the clod surface area.

The marked resistance of field-moist clods to breakdown by rainfall (compared with that of air-dried clods) was somewhat unexpected. For example, under calm conditions ($\bar{u}_o$), unprotected field-moist clods disintegrated only slightly more than did air-dried clods with 90 percent mulch cover (Table 4). Further testing revealed that neither aging nor storage caused moist clod resistance to raindrop disintegration (Fig. 2). Figure 2 also reveals that field-moist clods lose their resistance to detachment long before they become air-dry.

Immediately after exposure to rainfall, field-moist clods contained 25.07 percent water by weight (85 percent saturated) and air-dried clods, 45.77 percent. Water absorption was measured more precisely by placing air-dried, partially dried, and field-moist clods (all about 38 mm in diameter) in 30 ml of distilled water and allowing them to wet by capillary action up to 42 hr (Fig. 3). Additional measurements of clods that expanded by capillary wetting indicated a one-dimensional expansion of 15.7 percent, 3.7 percent, and 0.9 percent for air-dried, partially dried, and field-moist clods (average diameter, 22.6 mm), respectively. Apparently, because of their initial degree of water saturation (73 percent), field-moist clods

TABLE 5. SUMMARY OF ANALYSIS OF VARIANCE FOR SOIL DETACHMENT DATA.

Main effect	Variance ratio (F)	2-way interaction	Variance ratio
Kind of mulch (K)	0.6 ns	KC	1.6 ns
Cover (C)	527.1 **	KM	0.4 ns
Clod moisture (M)	4024.2 **	K$\bar{u}$	0.1 ns
Windspeed ($\bar{u}$)	2003.2 **	CM	185.7 **
		C$\bar{u}$	106.7 **
3-way interactions		M$\bar{u}$	1144.4 **
KCM	97.7**		
KC$\bar{u}$	56.1 **	4-way interactions	
KM$\bar{u}$	573.3 **		
CM$\bar{u}$	735.3 **	KCM$\bar{u}$	375.3 **

ns Nonsignificant.

** Significant at 1 percent probability level.

TABLE 6. THE EFFECT OF DIFFERENT MULCHES AND MOISTURE ON SOIL DETACHMENT BY RAINFALL FROM CLODS 12.7 TO 38 mm IN DIAMETER.

Kind of mulch	M_d 1.03 percent	M_w 20.84 percent	Mean
	Soil detached, pounds		
Wheat	0.904	0.247	0.567a*
Sorghum	0.910	0.231	0.570a
Corn	0.897	0.226	0.562a
Mean	0.904a*	0.234b	

*Means followed by same letter do not differ statistically at the 5 percent level.

TABLE 7. THE EFFECT OF MULCH COVER AND WINDSPEED ON SOIL DETACHMENT BY RAINFALL FROM CLODS 12.7 TO 38 mm IN DIAMETER.

Amount of cover	$\overline{u}_0$ 0 mph	$\overline{u}_{25}$ 25 mph	Mean
Percent	Soil detached, pounds		
0	0.480	1.175111	0.828a*
20	0.391	0.999	0.695b
50	0.294	0.660	0.477c
90	0.167	0.388	0.278d
Mean	0.333a*	0.805b	

*Means followed by same letter do not differ statistically at the 5 percent level.

TABLE 8. EFFECT OF INCLUDING ADDITIONAL VARIABLES ON THE SOIL DETACHMENT VARIANCE.

Variable added	R^2	ΔR^2, percent*
Clod moisture (M)	0.404	----
Windspeed ($\overline{u}$)	0.605	20.1
C$\overline{u}$	0.770	16.5
M$\overline{u}$	0.885	11.5
Cover (C)	0.909	2.4
CM	0.963	5.4

*Percentage of soil detachment variance accounted for by adding variablel indicated after each preceding variable has been considered.

absorb additional water slowly and thus resist erosion. Saturation water content of field-moist clods was computed to be 29.43 percent. About 42 hr were required to reach that water content by capillary wetting (Fig. 3). Probably, during the 45-min rainfall period, only a thin outer shell of the field-moist clods was saturated and was susceptible to raindrop detachment. In contrast, air-dried clods absorb water rapidly (in amounts greatly exceeding the liquid limit), expand, and with corresponding shear strength reduced to a low value are readily susceptible to raindrop impact or wind drag.

Rainfall accompanied by wind readily destroyed air-dried clods. On the average, 2.68 times more soil was detached in a 25-mph wind than when there was no wind (with rainfall intensity, duration of exposure, and clod size unchanged). The corresponding value was 1.65 for field-moist clods.

For air-dried clods, 90 percent cover in a 25-mph wind was no more effective in preventing soil detachment than was 20 percent cover under calm conditions (Table 4). Consequently, to determine cover requirements for reducing soil detachment and subsequent sediment transport, the probability of winds accompanying rain is an important consideration. Note that natural rain accompanied by wind would destroy clods more than was indicated in this study; kinetic energy of natural raindrops is higher (because of the wind component) than was that of the simulated raindrops of our study in which vector velocity was lower in wind than in still air (Disrud et al. 1969).

We oriented the mulch parallel with the flow so the wind would have its greatest effect. Orienting a 50 percent mulch cover normal to the flow over air-dried clods lowered the average soil detachment from 1.086 lb, for the parallel orientations, to 0.844 lb. Assuming a linear relationship between percentage of cover and soil detachment, 50 percent cover normal to wind direction provided the same protection as did 74 percent cover parallel with wind direction.

SUMMARY

The effects of vegetative mulches and initial soil moisture on soil detachment from clods by wind-driven rainfall were studied in a wind tunnel-raintower facility.

When the amount of mulch was expressed in percentage of soil cover, soil detachment did not differ among mulches of winter wheat, grain sorghum, and corn. As expected, soil detachment decreased with increased amounts of mulch cover.

Soil detachment from field-moist clods was markedly less than that from air-dried clods at similar levels of other variables studied. Apparently, field moist clods resist soil detachment by raindrops because additional water absorption is slowed by a high degree of saturation. In contrast, air-dried clods absorb water rapidly in excess of the soil's liquid limit, expand, and lose their

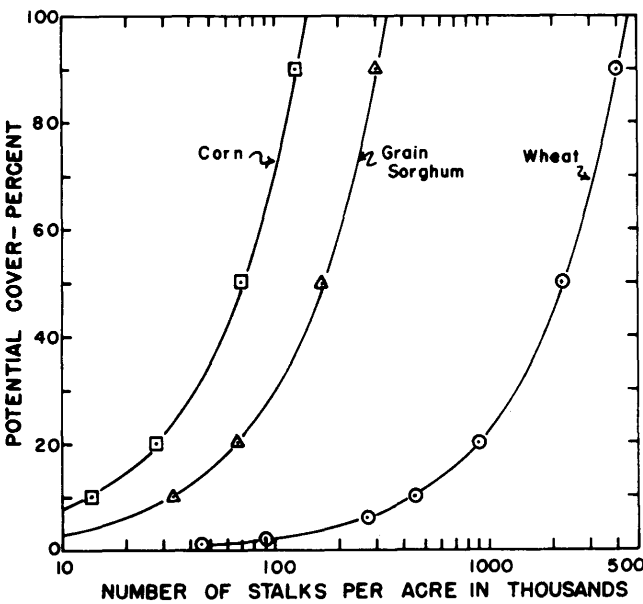

FIG. 1 Number of dry stalks of corn, grain sorghum, and wheat required to cover soil surface. Assumptions are 1-, 2-, and 4-ft lengths for wheat, grain sorghum, and corn, respectively; stalk diameters and densities are given in Table 3.

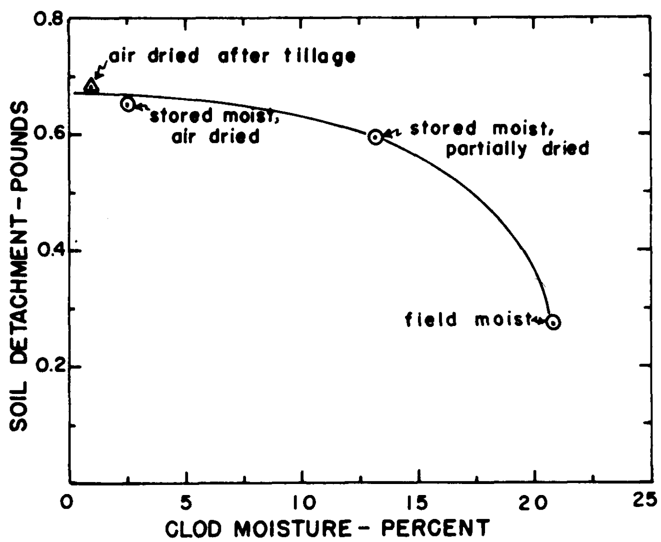

FIG. 2 Effect of storage and drying on soil detachment by rainfall from clods 12.7 to 38 mm diameter.

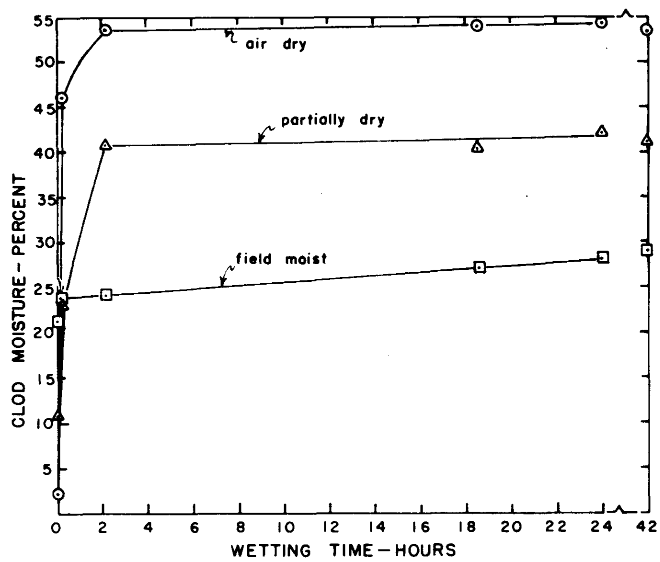

FIG. 3 Capillary moisture absorption, with initial moisture contents of 2.20, 10.81, and 21.29 percent, respectively, for air-dried, partially dried, and field-moist clods (38 mm diameter).

shear strength; thus, they are readily susceptible to raindrop impact or wind drag.

Rainfall accompanied by wind readily destroyed air-dried clods. On the average, 2.68 times more soil was detached in a 25-mph wind than when there was no wind. For air-dried clods, 90 percent cover in 25-mph wind was no more effective in preventing soil detachment than was 20 percent cover under calm conditions. Consequently, to determine mulch-cover requirements for different levels of protection, the probability of wind accompanying rain is an important consideration.

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