EFFECTS OF SURFACE ROUGHNESS ON EROSION OF SOIL BY WIND

by

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B. S., Kansas State University, 1961

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1962

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INTRODUCTION

Large areas of farm land in the High Plains of the United States become subject to wind erosion in the spring of the year. Wind erosion is more severe during this period because wind velocities are high and the soil has become finely divided and loose due to the action of freezing and thawing on the moist soil surface. Also contributing to this erosion problem is the depletion of residue cover due to decomposition and little or no growth of vegetation and to the drestruction of large soil clods during the winter. Soil movement by wind causes serious damage to crops. Accumulations of soil along field boundaries, fence rows, windbreaks and building sites are common. The formation of hummocks, dunes, drifts, and mounds in fields presents leveling and drainage problems. The removal of silt, clay and organic matter not only reduces the natural fertility of the soil but leaves a sandier surface which is more susceptible to further wind erosion.

There are many methods devised to prevent soil movement by wind. Stubble mulching and returning poor sandy land to grass are two of the preventive methods. Once soil movement has started, the most common practice to stop it is emergency tillage. This type of tillage ridges and roughens the soil surface and brings clods to the surface to protect the smaller soil particles.

More knowledge should be obtained on how much soil roughness is needed to control soil movement by wind most effectively. The study reported in this thesis was undertaken in an attempt to supply more knowledge on this subject.

REVIEW OF LITERATURE

A review of the literature on the effects of soil roughness reveals that research on the effects of ridge heights has received little attention as compared to research on the effects of soil cloddiness.

Chepil (3) stated that the amount of soil erodible by wind is limited by the height of and distance between the nonerodible fractions which are exposed to wind. These nonerodible fractions are larger than 0.84 mm. in diameter. Some of them are at least several inches in diameter. They are commonly called clods. Chepil (2) reported that a cloddy surface reduces the erosive capacity of the wind by retarding the wind velocity near the surface. Chepil and Woodruff (7) affirmed that the amount of residue cover needed to control wind erosion varies inversely with the degree of soil cloddiness. The importance of clods in controlling wind erosion has been discussed by other investigators (9), (12), (16).

The effect of ridges alone has received little attention. Chepil and Woodruff (6) reported that the degree of surface roughness depends on size, shape, and lateral frequency of clods, ripples, and ridges and on height, length, density, and quality of vegetative cover. Because the effects of vegetation and soil roughness are hard to measure, a "ridge roughness equivalent" was devised (18). It is expressed in terms of effects of ridges composed of fine gravel 2.0 - 6.4 mm. in diameter and having a height - spacing ratio of 1.4. For example, if the ridge roughness equivalent is four inches, the surface has a roughness and resists wind to the same degree as the standard gravel ridges four inches high and sixteen inches apart at right angles to the direction of the wind.

The first research directly on the effects of ridges was done by Chepil and Milne (5). They used a smooth surface and a ridged one with ridges 2.5 inches high and two soils - a dune material and a cultivated soil. They found a reduction in initial rate of flow for both soils for ridges as compared to a smooth surface. The total quantity of material eroded from the cultivated soil varied more or less proportionately with the initial rate of soil flow. The ridges on dune material disappeared so rapidly that their effect was almost nil, but on the cultivated soil, clods protected the ridges which remained at nearly their original height after all the erodible soil fractions had been removed from the surface and movement had ceased. The ridges not only sheltered and trapped soil particles in the furrows between the ridges, but lowered the average wind velocity for some distance above the average soil surface. Counteracting these beneficial effects was the increase in wind velocity at the crests of ridges and the general increase in eddying of the wind. The former set of factors outweighed the latter and a decrease in intensity of erosion was measured for a ridged as compared to a smooth surface.

Much research has been done to determine which farm implements will give the best combination of ridge roughness and soil cloddiness when used for emergency tillage. Some examples of this research include studies on the effect of type and speed of operation of the chisel point cultivator (16) and other implements commonly found on farms (7), (8), (14), (15). Lyles and Woodruff (10) studied the effect of soil moisture at the time of tillage on percent and durability of clods formed by three different implements.

DESCRIPTION OF EXPERIMENTAL EQUIPMENT

Wind Tunnel

The laboratory wind tunnel employed in this study has been described by Zingg and Chepil (17). The characteristics of wind velocity distribution developed throughout the length of the tunnel were described in the same paper (17).

Air Measuring Devices

A pitot tube was used to measure wind velocities above the floor of the tunnel. Control of height of measurement above the tunnel floor was facilitated by clamping the vertical brass tubing to a graduated vernier-type point gage. The pitot tube was located 22 feet downwind from the honeycomb in the center of the tunnel.

An alcohol manometer inclined at 3 degrees from the horizontal was used to register air velocity pressures. This manometer was constructed in the laboratory for general use. Values of wind velocity obtained are for standard temperature and atmospheric pressure, i.e., 70°F at sea level.

Test Area

The test area (Figure 2, Plate I) was composed of a tray, 64 inches long, 18.5 inches wide, and three inches deep. The windward edge of the tray was located 30 feet downwind from the honeycomb. Three modified Bagnold soil catchers (p. 80 of 1) were spaced evenly across the downwind edge of the tray to sample the soil that had eroded from the tray. The bottom of the catchers passed through the floor of the tunnel to facilitate sampling (Figure 1, Plate I).

DESIGN OF EXPERIMENT

The experiment was designed so statistical analysis for a fixed-effects, 6 x 4 x 3 factorial design could be used. All treatments were duplicated.

Dune sand used in this study was obtained near Abilene, Kansas. This soil material was oven-dried and sieved to remove all particles larger than 0.84 mm. in diameter. Cultivated soils were simulated by mixing different proportions of erodible and nonerodible materials. Erodible material was sand dune. Nonerodible material was gravel, 2.0 - 6.4 mm. in diameter. Gravel was used instead of soil clods because it does not break down with handling and therefore facilitates maintenance of exact percentages of erodible and nonerodible fractions. To obtain complete mixing, a concrete mixer was used.

Wind velocities used in this experiment were 27, 30, and 33 miles per hour at one-foot height. This was above the fluid boundary layer next to the ground surface in that part of the tunnel where the tests were

EXPLANATION OF PLATE I

Fig. 1. Side view of Bagnold catchers and sampling area with cans in place.

Fig. 2. Test area showing tray, catchers, and a soil in place for testing.

PLATE I

Fig. 1.

Fig. 2.

conducted. For any given natural wind, the velocity near the ground varies with the roughness of the ground surface. Hence, velocity near the ground carries little meaning. However, the so-called drag velocity for any wind remains the same no matter how rough the surface. Therefore, it was necessary to express wind velocity in the tunnel in terms of drag velocity. The drag velocity is the rate of increase of velocity with $\log_{10}$ of height. According to the Prandtl (11) and von Karman (13), the drag velocity V* is equal to

$$V_* = \frac{30k}{8.5} \quad (1)$$

where k is the height at which the velocity is zero as shown by an example obtained over 0.5 inch ridges, Figure 1.

Drag velocity was maintained constant over different degrees of roughness of surface. The drag velocities used on each roughness of surface were 86, 95, and 105 cm. per second.

The surface was smoothed down with a straightedge for the so-called "smooth" surface. It was estimated to have a ridge roughness equivalent of about 0.12 inch. Ridges 0.5, 1.0, 2.0, 4.0, and 8.0 inches high with a height-spacing ratio of 1:4 were used. These, according to Zingg and Woodruff (18), correspond to ridge roughness equivalent of 0.5, 1.C, 2.0, 4.0, and 8.0, respectively.

Plate I shows the orientation of all experimental equipment. It shows the nonerodible gravel occupying the foreground and the area on both sides of the test area and also the soil in place for testing.

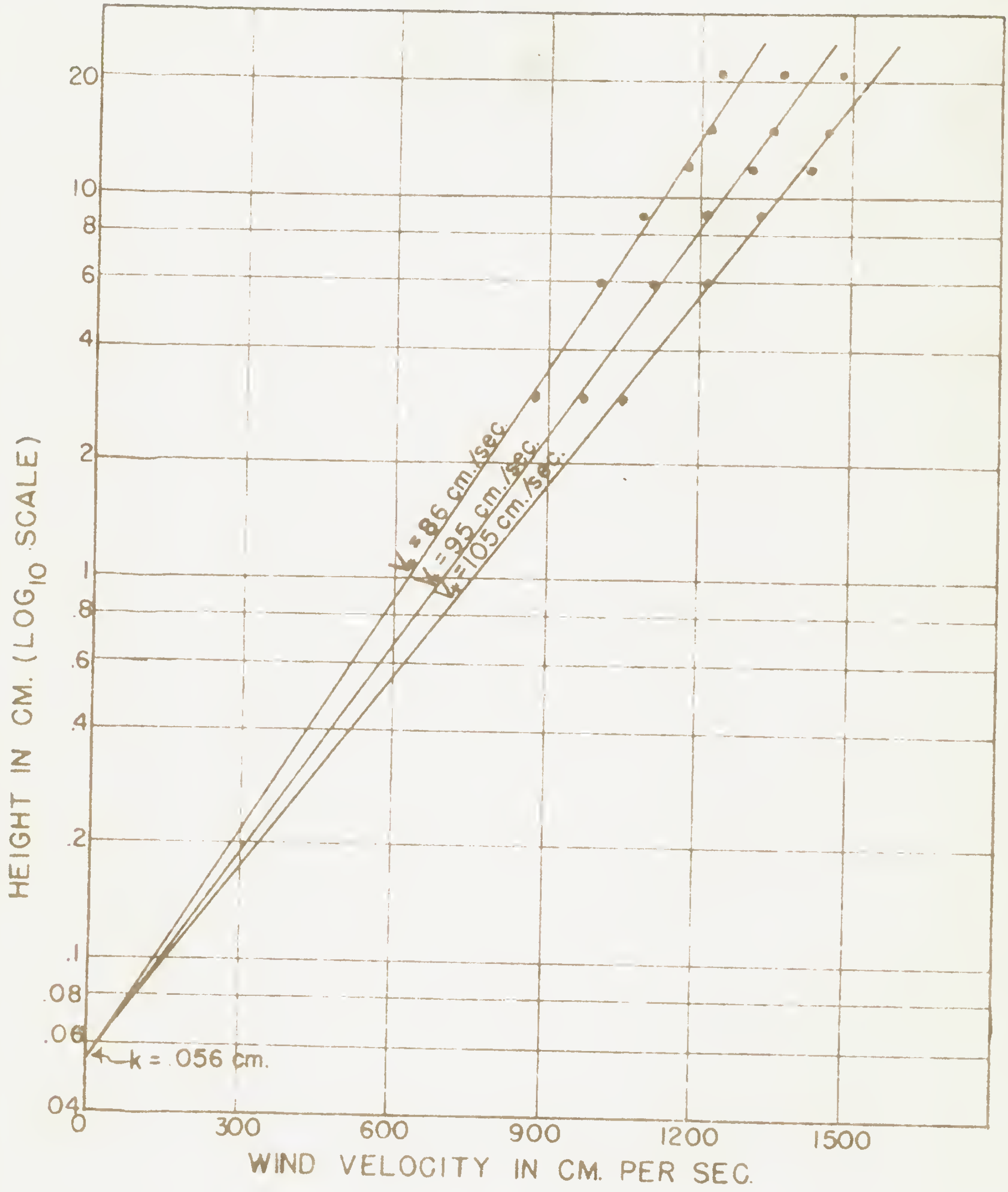

Figure 1. Distribution of wind velocity with height over 0.5 inch ridges.

PROCEDURE

The tests were conducted in the following manner. First, the surface roughness to be tested was constructed on the tray and on the foreground portion of the tunnel, using nonerodible gravel. The fan speed and intake vane were set, using the total pressure, designated as P_1, in the area between the blower and the honeycomb as an indicator of general wind velocity. Velocities at various heights above the gravel surface were then measured. The gravel ridges were removed from the tray and soil ridges were constructed in their place and exposed to the wind for 10 minutes or until just before the tray bottom was exposed. Soil samples were taken every 30 seconds for the first three minutes and every minute thereafter. At the end of ten minutes the blower was stopped, soil samples were weighed and recorded, and the next soil ridges constructed. After all four soils were exposed, the fan speed and intake vane were reset and the process repeated. One man could easily operate the tunnel and obtain all experimental data.

The 10-minute exposure of soil to wind removed all or most of the erodible material from the soil surface. For cases where removal was not complete, the total quantity of erodible material was estimated. To estimate the total quantity of erodible soil material, the cumulative soil loss curve was plotted and extended to a time period at which a constant rate would be obtained. The corrected amounts thus obtained generally varied little from the amounts obtained at the end of the 10-minute period. Only the initial rate of soil flow was measured for dune material containing no nonerodible soil fractions because such materials never stabilize but continue to erode indefinitely.

RESULTS

Effect of Ridge Height on Erosion of Dune Materials

The lowest rate of soil flow was associated with ridges 2 inches high (Table 1). The rate of soil flow increased as ridge height increased or decreased from this height. The rate of flow over ridges 4 and 8 inches high, although higher than for the 2 inch ridges, was not as high as for a smoothed surface under low wind velocities. At higher wind velocities the 8 inch ridges were more erodible than the smoothed surface. Thus, the higher the wind velocity, the less effective were the ridges in reducing the rate of movement of dune materials.

Table 1. The effect of surface roughness on rate of flow of dune material exposed to different wind velocities.

Ridge Roughness	Drag velocity in cm/sec		
Equivalent	86	95	105
inches	gm/cm width/sec	gm/cm width/sec	gm/cm width/sec
0.12	0.32	0.43	0.55
0.5	0.27	0.36	0.48
1.0	0.24	0.35	0.50
2.0	0.16	0.28	0.45
4.0	0.23	0.32	0.47
8.0	0.26	0.45	0.57

Downward and backward movement of soil particles occurred on the lower 2/3 to 3/4 of the windward side of each ridge. This downward and backward movement was most severe on the 8-inch ridges and not noticeable on the 2-inch ridges.

The erodible soil particles accumulated between ridges which were not completely leveled by wind. The accumulations occurred principally on the leeward side of each ridge and not particularly at the bottom of the furrow. The areas of removal and direction of movement are shown in Figure 2.

Effect of Ridge Height on Erosion of Simulated Cultivated Soils

Rate of flow and total quantity of erodible soil material are presented in Tables 2 and 3, respectively.

Total quantity of erodible material and initial rate of soil flow for each ridge height and wind velocity decreased with an increase in percent of nonerodible soil fractions. The trend for rate of flow established by dune sand was followed by soils containing 6 and 12 percent nonerodible fractions. The soil containing 28 percent of nonerodible fractions had its lowest rate of flow when ridges were only 0.5 inch. The quantity of erodible material increased directly with height of ridge above the 0.5 inch height. But even on this soil the initial rate of soil flow was considerably lower over 8-inch ridges (the largest used) than over a smoothed surface.

The 0.5 and 1 inch ridges on the soil containing 6 percent nonerodible soil fractions were completely flattened under all three wind

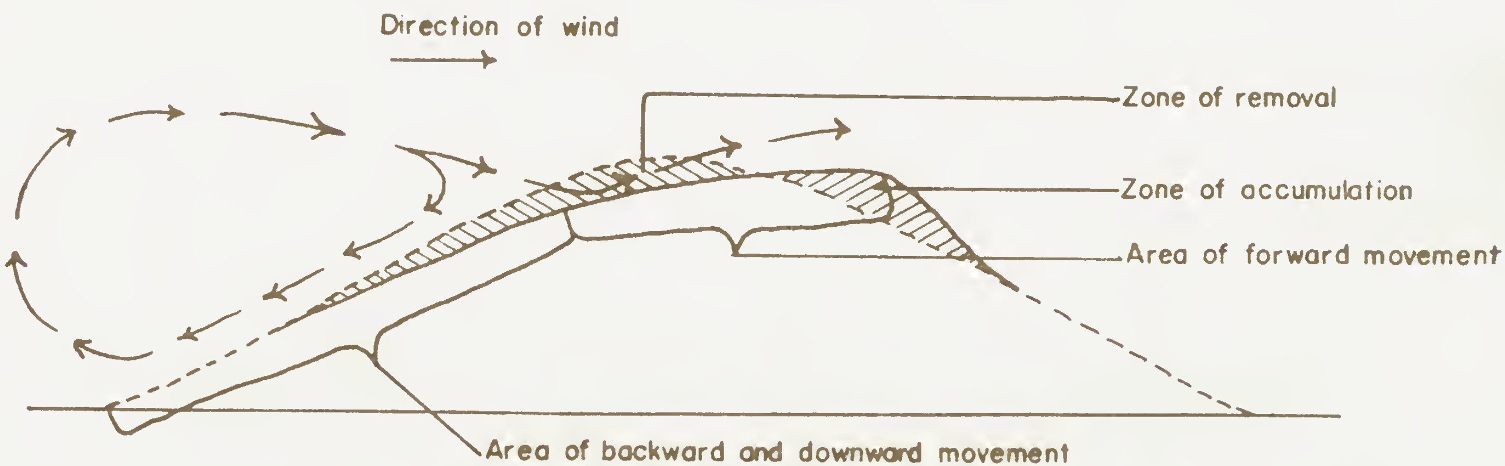

Figure 2. A sketch of the zones of removal, accumulation, and areas of movement.

Table 2. The effect of surface roughness on the initial rate of flow of three simulated cultivated soils exposed to different wind velocities.

Soil Cloddiness %	Ridge Roughness Equivalent inches	Drag velocity in cm/sec 86 gm/cm width/sec	95 gm/cm width/sec	105 gm/cm width/sec
6	0.12	0.33	0.44	0.58
	0.50	0.25	0.38	0.52
	1.0	0.22	0.35	0.50
	2.0	0.15	0.28	0.43
	4.0	0.18	0.30	0.40
	8.0	0.21	0.36	0.49
12	0.12	0.33	0.44	0.58
	0.50	0.20	0.31	0.44
	1.0	0.15	0.25	0.36
	2.0	0.13	0.23	0.33
	4.0	0.17	0.23	0.30
	8.0	0.19	0.31	0.40
28	0.12	0.28	0.37	0.44
	0.50	0.04	0.06	0.10
	1.0	0.05	0.07	0.11
	2.0	0.05	0.09	0.14
	4.0	0.09	0.14	0.19
	8.0	0.11	0.18	0.26

Table 3. The effect of surface roughness on total quantity of eroded material from three simulated cultivated soils exposed to different wind velocities.

Soil Cloddiness %	Surface Roughness inches	Drag velocity, cm/sec 86 Tons/Acre	95 Tons/Acre	105 Tons/Acre
6	0.12	51	63.5	85.0
	0.50	27.0	47.5	74.5
	1.0	26.0	38.5	60.0
	2.0	17.0	27.0	35.5
	4.0	17.0	27.0	30.0
	8.0	19.0	31.0	49.0
12	0.12	14.5	23.4	24.5
	0.50	9.0	15.5	20.0
	1.0	8.0	11.5	16.5
	2.0	6.5	11.0	15.0
	4.0	8.6	10.0	13.5
	8.0	9.5	15.5	20.0
28	0.12	5.0	6.0	8.5
	0.50	1.0	1.5	2.5
	1.0	1.2	1.7	2.3
	2.0	1.5	2.2	3.3
	4.0	2.9	3.8	5.2
	8.0	4.8	6.3	9.5

velocities before soil movement ceased. On soils containing more than 6 percent nonerodible fractions, some semblance of ridges remained after soil movement ceased. The erodible soil particles in these cases accumulated in the furrow between the ridges, principally on the leeward side of the ridges.

The strength of the wind on the lower portion of the windward side of the ridges was sufficient to move some of the nonerodible fractions backward and downward. Considerable amounts of the nonerodible fractions were thus removed from an area $\frac{1}{4}$ the distance down from the crest of the ridge. The nonerodible fractions in these cases were deposited evenly over the bottom $\frac{1}{2}$ of the ridge. The nonerodible fractions moved in short hops and not in a continuous motion, indicating periodic strong eddies.

The higher the wind velocity, the higher the ridges had to be to produce the lowest quantity of erodible soil material. Thus, for a drag velocity of 86 centimeters per second the most effective ridges were 2 inches high, and for 95 and 105 centimeters per second drag velocity the most effective ridges were 4 inches high.

The initial rate of flow was found to vary more or less proportionately with total quantity of erodible material.

The statistical analysis based on a fixed-effects 6 x 4 x 3 factorial design and the LSDs for the main effects are shown in Table 4. All main effects and interactions were significant at the $\frac{1}{2}$ of 1 per-cent level. The LSDs show that each ridge height, each percent of nonerodible fractions, and each drag velocity was significantly different from any other in that same category.

DISCUSSION OF RESULTS

The lower rate of soil flow over a ridge surface as compared to a smooth surface seems to be due to trapping of soil particles between the ridges and to a reduction of the average wind velocity. These factors appeared to be dominant for ridges 2 inches or less in height when wind velocity was relatively low and for ridges 4 inches in height when wind velocity was relatively high. Greater wind velocities than those used might have required ridges considerably greater than 4 inches in height to be most effective in controlling wind erosion.

Ridges tend to increase the velocity at the crests where most erosion occurs. They also tend to increase wind turbulence which in turn tends to increase erosion by wind. When these factors become dominant for a certain height of ridge, the rate of flow and total quantity of erodible material increases with an increase in height.

The initial rate of flow and total quantity of erodible material for the cultivated soils was always lower for ridged than for smoothed surface. This was not true for dune materials where the initial rate of flow became higher for ridges than for the smoothed surface.

The total quantity of erodible soil varies more or less proportionately with the initial rate of soil flow. Because of this relationship and because plant damage by wind erosion is related to the rate and amount of soil particles which strike the plants, the effect of ridges on lowering the rate of soil flow is very important.

In conclusion, the results of this study show that any amount of

Table 4. Statistical analysis of a fixed effect 6 x 4 x 3 factorial experiment and LSD for main effects.

Source of variation		Degrees of freedom	Sign or nonsign
Main effects			
Replications		1	Nonsign
Ridge heights	(A)	5	Sign*
Soils	(B)	3	Sign*
Winds	(C)	2	Sign*
Interactions			
A x B		15	Sign*
A x C		10	Sign*
B x C		6	Sign*
A x B x C		30	Sign*
Error		71	
Total		143	

* Sign at 0.5 percent level.

LSD for soil roughness = 0.300

Soil roughness	0.12	8.0	0.50	1.0	4.0	2.0
Ranked means	16.16	12.05	10.84	10.02	9.66	8.65

LSD for soil cloddiness = 0.246

Soil clods in percent	0	6	12	28
Ranked means	14.17	13.48	11.40	5.87

LSD for drag velocities = 0.212

Drag velocities	105	95	86
Ranked means	15.25	11.12	7.32

ridging on a cultivated soil is better than a smooth surface. However, the capacity of ridges to trap the soil and reduce wind velocity varies with height of ridges, degree of soil cloddiness, and wind velocity.

SUMMARY

The rate of soil flow under a wind force was found to vary inversely with the roughness of the surface up to 0.5 to 4 inches depending on soil cloddiness and wind velocity. The trapping of soil particles between ridges and the decrease in average wind velocity were dominant on smaller ridges up to about 2 inches in height. For ridges larger than 2 inches the dominant factors were a higher wind velocity at the crest of the ridges and an increase in eddying of the wind.

An increase in percent of nonerodible fractions substantially decreased erosion under all wind velocities. The greater the percent of nonerodible fractions in the soil the lower was the height of ridge that was most effective in reducing wind erosion. On the other hand, the higher the wind velocity the higher the ridges had to be for maximum effectiveness.

ACKNOWLEDGMENT

The research reported is cooperative between the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. D. A. and the Kansas Agricultural Experiment Station.

Appreciation is acknowledged to Dr. W. S. Chepil and F. H. Siddoway for guidance and suggestions during these investigations and in the preparation of the final manuscript.

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The object of this investigation was to obtain more knowledge on the magnitude of soil surface roughness that is needed to control soil movement by wind. This knowledge is basic for determining the effects of different farm implements when used to control wind erosion with emergency tillage.

A review of the literature revealed that little research on the effects of ridge heights had been done in comparison to research on the effects of soil cloddiness.

A laboratory wind tunnel and supplementary equipment was used in this study. A dune material less than 0.84 mm. in diameter was used alone and in combination with nonerodible gravel to simulate cultivated soils. A smoothed surface and ridged surfaces with ridges of 0.5, 1, 2, 4, and 8 inches high were used on soils with 0, 6, 12, and 28 percent nonerodible fractions. The soils were exposed to three wind velocities, 27, 30, and 33 miles per hour at one-foot height, for 10 minutes. Both rate of flow and total quantity of erodible soil were measured.

With dune material (that with 0 percent of nonerodible fractions) the lowest initial rate of flow was obtained with 2-inch ridges. The initial rate of flow increased as ridge height increased or decreased from this height. The highest initial rate of flow was for a smoothed surface at low wind velocities and for 8-inch ridges at high wind velocities.

The simulated cultivated soils with 6 and 12 percent nonerodible fractions had the lowest initial rate of flow and total quantity of erodible material when ridges were 2-inches high. The initial rate of flow and total quantity of erodible material increased as ridge height increased or decreased from this height. The smoothed surface always gave the highest initial rate of flow and the total quantity of erodible material. The soil with 28 percent nonerodible fractions had its minimum loss with 0.5 inch ridges and an increase with height thereafter.

On simulated soils the higher the wind velocity the higher the ridge had to be for greatest effectiveness.

On dune material and on simulated cultivated soils, downward and backward movement of soil particles occurred on the lower 2/3 to 3/4 of the windward side of the 4 and 8 inch ridges but no such movements could be detected with smaller ridges. The forces that caused the downward and backward movement of soil particles were strong enough to move the nonerodible fractions in short hops.

The rate of flow varied more or less proportionately with the total quantity of erodible material.

Results with ridges 2 inches or less in height generally agreed with the previously reported works on the subject.

Results with ridges greater than 2 inches in height indicated one important finding, namely, that for some wind velocities and soil structure ridges may be higher than necessary to control wind erosion most effectively.