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Effects of Ridges on Erosion of Soil by Wind[1]

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ABSTRACT

The effect of ridges on soil erosion by wind was studied under laboratory conditions with wind tunnels. Smoothed soil surface and 1.3, 2.5, 5.1, 10.2, and 20.3 cm. high ridges constructed of dune sand and three simulated cultivated soils were exposed to six wind velocities ranging from 47 to 83 miles per hour. Ridges 5.1 to 10.2 cm. high eroded little due to trapping of soil particles between ridges and average wind velocity decrease. Ridges less than 5.1 cm. high were not as effective in trapping soil particles and reducing wind velocities. Extensive erosion on ridges higher than 10.2 cm. resulted from higher wind velocities at the ridge crests and increased wind eddying.

Soil surface roughness composed of anchored vegetative material, soil ridges, soil clods, or combinations of the three help control wind erosion by lowering the wind velocity near the soil surface and by sheltering erodible soil fractions. Chepil and Woodruff (3) asserted that the magnitude of surface roughness depends on height, length, density, and quality of vegetative cover and on size, shape, and lateral frequency of clods, ripples, and ridges.

So far as the authors are aware, the only previous research on direct effects of ridges on soil erosion by wind was by Chepil and Milne (2). Their results indicated: (*a*) ridges 2.5 inches high placed at right angles to the wind reduced erosion rates to ¼ to ⅓ the rate from a smooth surface, (*b*) ridges constructed of natural dune material eroded quickly and had almost no wind erosion controlling effect, (*c*) on cultivated soils, clods protected the ridges and maintained them near their original height, (*d*) ridges reduced erosion by reducing the wind velocity at the average soil surface and by trapping soil particles in the furrows between ridges, and (*e*) nonbeneficial effects of ridges included increased wind velocity at ridge crests and increased wind eddying.

It was the purpose of this research to evaluate the relative effects of ridge heights with varying degrees of simulated cloddiness on soil erosion by wind.

MATERIALS AND METHODS

Two laboratory experiments were conducted to determine effects of various ridge heights on erodibility of dune sand and simulated soils composed of mixtures of dune sand and gravel. Experiment 1 was carried out in the laboratory wind tunnel (8) and experiment 2 in a modified portable tunnel (7) ordinarily used for testing field surfaces. For these tests it was placed on the lawn outside the laboratory. A factorial design was used in both experiments. Treatments were replicated from 4 to 6 times. Treatment variables were ridge height, wind velocity, and soil cloddiness.

A pitot tube and alcohol manometer were used to measure the vertical wind velocity profile above the soil surface. These velocities were plotted against $\log_{10}$ height, and the zero velocity-height intercept was determined graphically. The drag velocity was then calculated from the relationship given by Bagnold (1)

$$v_z = 5.75\, V_* \log(z/k) \qquad [1]$$

where

V_* = drag velocity,

k = velocity-height intercept, and

v_z = velocity at reference height z.

Erodible and nonerodible constituents were used in the simulated soils. The erodible portion was dune sand less than 0.84 mm. in diameter. The nonerodible portion was natural gravel 2.0 to 6.4 mm. in diameter. The two materials were mixed to simulate soils with 0, 6, 12, and 28% of clods greater than 0.84 mm. in diameter. Gravel was used rather than natural soil clods because clods break down with repeated handling and therefore present difficulty in maintaining uniform proportions of erodible and nonerodible constituents.

Experiment 1

The test soils were placed in a 162.6 by 47.0 cm. tray 7.6 cm. deep. The top of the tray was level with the tunnel floor. The windward edge of the tray was 9.14 m. downwind in the tunnel. Ridges running at right angles to wind direction were constructed on the soils in the tray with one-half the volume of the ridges above and one-half below the level of the tunnel floor.

The tunnel floor in the foreground and the leeward side of the soil test area were composed of gravel 2.0 to 6.4 mm. in diameter, leveled with a straight edge to form a so-called "smooth surface".

Ridges tested for erodibility were 1.3, 2.5, 5.1, 10.2, and 20.3 cm. high and had a height-spacing ratio of 1:4. A surface without any ridges (smooth surface) was also tested for erodibility.

Three modified Bagnold soil samplers (1) were spaced evenly across the downwind edge of the tray to determine rate and total quantity of soil erosion from the tray. The bottom of the samplers passed through the floor of the tunnel to facilitate sampling. Samples were taken every 30 seconds for the first three minutes, then every minute until soil movement ceased.

Constant drag velocities of 90, 99, and 108 cm. per second were used on each ridge roughness and each soil. Assuming a logarithmic representation of wind profile (4, 5) and interpreting in terms of wind velocities at heights usually reported by U. S. Weather Bureau Stations, those drag velocities correspond to wind velocities of 47, 51.5, and 56 miles per hour at 50 feet above a smooth fallow surface that has a zero velocity-height intercept equal to 0.005 foot.

The relative erodibility of ridged and smooth soil surfaces was measured two ways: (*a*) by determining the rate of soil movement during the initial 30 seconds of exposure to wind, and (*b*) by determining total quantity of material eroded from the test area. The initial 30 second rate is given as the effect of the ridges at their original height. Erosion ceased only when nonerodible material was present in the soil.

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Table 1—The effect of height of ridges on total quantity of eroded material from three simulated cultivated soils exposed to different drag velocities, experiment 1.

% soil cloddiness	Height of ridges	Total quantity of eroded material for drag velocity of 90 cm./sec.	99 cm./sec.	108 cm./sec.
	cm.	kg./m.^{2} *		
6	0	11.43	14.23	19.05
	1.3	6.05	10.65	16.70
	2.5	5.83	8.63	13.45
	5.1	3.81	6.05	7.96
	10.2	3.81	6.05	6.72
	20.3	4.26	6.95	10.98
12	0	3.25	5.24	5.49
	1.3	2.02	3.47	4.48
	2.5	1.79	2.58	3.70
	5.1	1.46	2.46	3.36
	10.2	1.93	2.24	3.02
	20.3	2.13	3.47	4.48
28	0	1.12	1.34	1.91
	1.3	0.22	0.34	0.56
	2.5	0.27	0.38	0.52
	5.1	0.34	0.49	0.74
	10.2	0.65	0.85	1.16
	20.3	1.08	1.41	2.13

*(kg./m.^{2})/0.22413 = tons/acre.

Experiment 2

This experiment was conducted in a portable field tunnel 1.52 m. high, 0.61 m. wide, and 9.11 m. long to see if laboratory tunnel results were confirmed. A tray 304.8 cm. long and 43.2 cm. wide oriented with its long sides parallel with the wind had a soil test area in its center 162.6 cm. long and 43.2 cm. wide. The ridges were constructed across the width of the tray. The 71.1 cm. on each end of the tray were composed of nonerodible gravel ridges of the appropriate height. The tray was suspended on four 2.5 cm. steel beams with an electrical strain gauge on each beam to measure the loss of the soil from the tray to an accuracy of ± 5 g. The windward edge of the tray was 6.10 m. downwind from the windward end of the tunnel.

The foreground was composed of appropriate size ridges of 2.0 to 6.4 mm. diameter gravel. Ridges were constructed with their full height above the tunnel floor on both the foreground and in the soil test area.

Test surfaces were composed of a smooth surface and of ridges 2.5, 5.1, 10.2, and 20.3 cm. high with a height-spacing ratio of 1:4.

Constant drag velocities of 126, 144, and 162 cm. per second were used on each soil surface and soil. The drag velocities correspond to wind velocities of 65, 74, and 83 miles per hour at 50 feet above a smooth fallow surface that has a zero velocity-height intercept equal to 0.005 foot. The differences in drag velocities between tunnels is due to the characteristics of the two tunnels.

Only dune sand and a simulated soil with 28% cloddiness were used and only the rates of erosion during the initial 30 seconds of exposure were determined. Only 30-second rates were measured because of the relationship between initial rate of soil flow and total quantity of eroded material found in experiment 1.

RESULTS

Experiment 1

The initial rate of soil flow and the total quantity of eroded material varied more or less proportionally with each other (Fig. 1 -A, -B, -C, -D, and Table 1). For convenience, the two aspects of erosion are therefore referred to as erodibility.

On soils containing 6 to 12% nonerodible fractions (Fig. 1-B and 1-C) the higher the wind velocity the higher the ridges required to maintain lowest erodibility. Thus, for a drag velocity of 90 cm. per second the most effective ridges were 5.1 cm. high, and for a drag veloci-

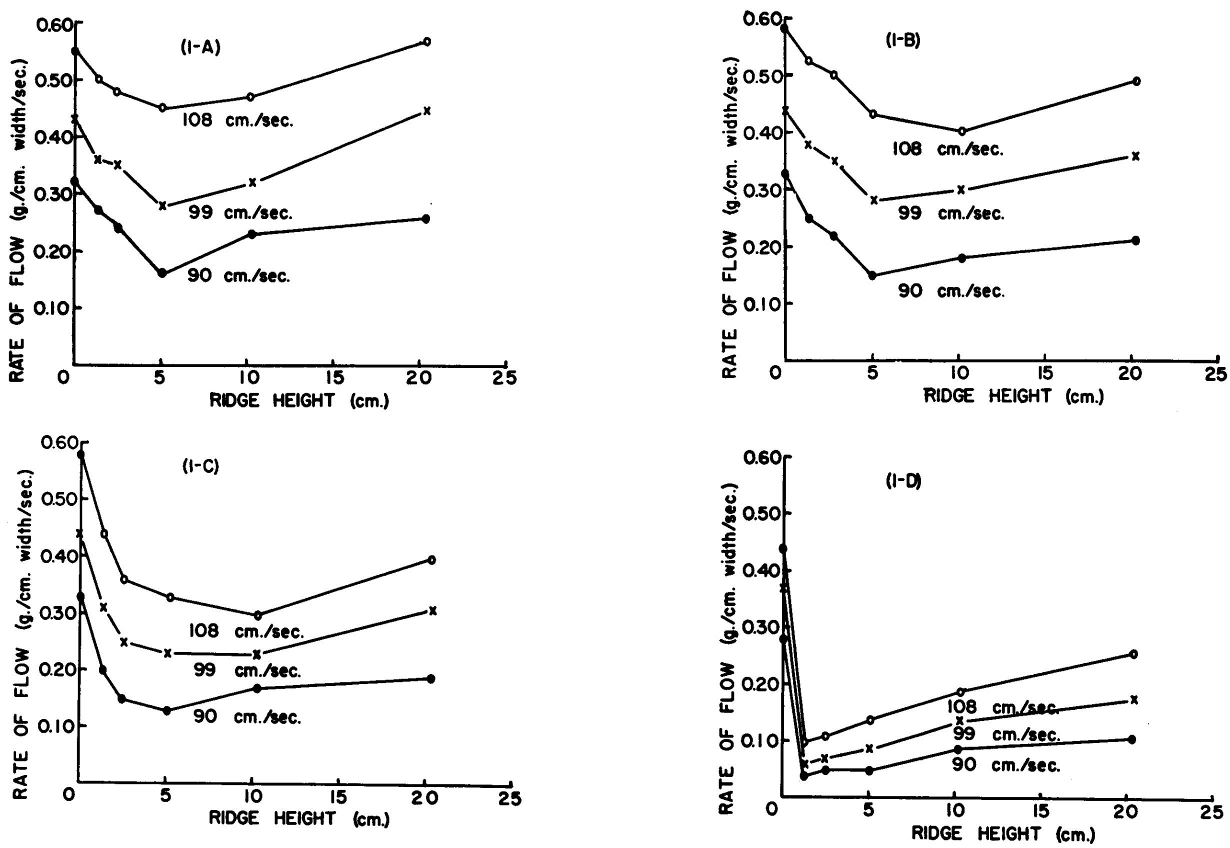

Fig. 1—Effect of height of ridges on initial rate of flow for 0% (1-A), 6% (1-B), 12% (1-C), and 28% (1-D) cloddy soils exposed to three drag velocities.

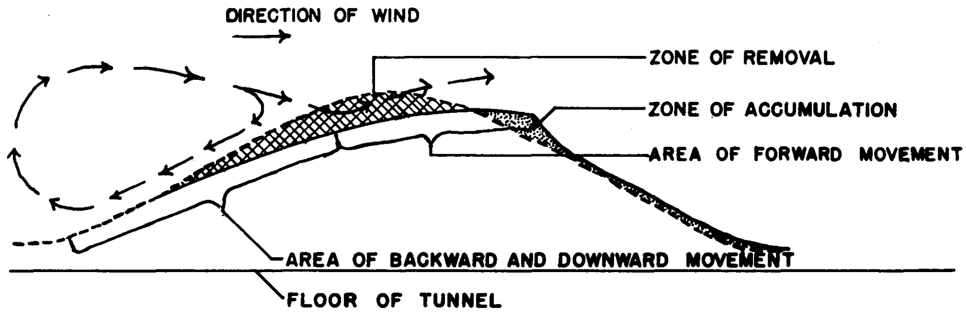

Fig. 2—Cross section of a ridge indicating zones of soil removal, accumulation, and direction of movement when wind blows at right angles to the ridge. This effect was observed in both tunnels.

ty of 108 cm. per second the most effective ridges were 10.2 cm. high. However, the differences in erodibility between the 2.5, 5.1, and 10.2 cm. ridges were far smaller than the differences between any of the ridges and the smooth surface.

The erodibility of 20.3 cm. ridges exceeded that of smooth surface when drag velocities were 99 or 108 cm. per second on a soil containing 0% nonerodible fractions (Fig. 1-A). On all other soils, erodibility of 20.3 cm. ridges was considerably lower than erodibility of the smooth surface.

Ridges 1.3 and 2.5 cm. high on soil containing 6% nonerodible soil aggregates were completely flattened under all three drag velocities before soil movement ceased. On soils containing more than 6% nonerodible fractions, at least a portion of each ridge remained after soil movement ceased.

Wind velocities at the crest of the ridges changed in relation to the erodibility of the ridges (Table 2).

Removal of erodible soil particles was observed to occur only from the upper two-thirds of the windward side of the ridges (Fig. 2). From the upper half of this region, removal was along the general direction of the wind. Some of the highly erodible particles, once lifted from the surface, continued to bounce across the ridges or float through the air. Other highly erodible particles were deposited on the leeward sides of the ridges. Coarse, semierodible particles merely rolled or jumped over the crests and were deposited on the leeward sides of the ridges. Semierodible particles moved in short hops and not in continuous suspension. This hopping motion was most pronounced on 20.3 cm. ridges and least noticeable on 5.1 cm. ridges.

Experiment 2

This experiment generally confirmed results of experiment 1, with one minor exception. The lowest initial rate of soil flow was attained with 5.1 cm. ridges (Table 3), rather than with 1.3 to 10.2 cm. ridges, depending on soil cloddiness and drag velocity, as in experiment 1. However, differences in the rate of soil flow between 1.3 and 10.2 cm. ridges (Table 3), were relatively small and for all practical purposes these ridges may be considered about equally resistant to erosion.

Statistical analyses for experiment 1 and 2, based on the fixed effects factorial design, indicate that all main effects and interactions were significant at the 0.005 level.

DISCUSSION

The lower rate of soil erosion over a ridged surface as compared to a smooth surface seems to be due to trapping of soil particles between ridges and to general reduction of wind velocity above the surface. Those factors appear to be dominant for ridges 5.1 cm. or less in height when drag velocities are relatively low and for ridges 10.2 cm. or less in height when drag velocities are relatively high. Higher drag velocities than those used might have required ridges considerably greater than 10.2 cm. high to be most effective. However, such high velocities are rare. Transposing equation 1 to:

$$V_* = \frac{V_z}{5.75 \log (z/k)} \qquad [2]$$

we see that if V_* and z are held constant and the surface roughness k is increased, then the velocity at the point z must decrease.

Ridges above a critical height, tend to increase wind velocity at the crests where most erosion occurs. They also tend to increase wind turbulence which, in turn, tends to increase erosion of soil by wind. These two factors are dominant for ridges higher than 5.1 to 10.2 cm.; the higher the ridges above this crucial maximum, the greater the amount of soil erosion.

The amount of plant damage by wind erosion varies directly with the amount of soil movement (6). Planting between ridges is very important because the ridges lower the rate of soil flow and reduce the damage to plants when they are young and most susceptible to wind erosior damage.

Table 2—Wind velocities in cm. per second at the ridge crests for each ridge height and drag velocity.

Height of ridges	Wind velocities at crest of ridges with drag velocities of		
	90 cm./sec.	98 cm./sec.	108 cm./sec.
cm.		cm./sec.	
0	471	509	564
1.3	421	471	523
2.5	413	463	509
5.1	394	455	447
10.2	404	413	430
20.3	487	502	551

Table 3—The effect of ridge height on the initial rate of flow of two simulated soils exposed to different drag velocities in the portable tunnel.

% soil cloddiness	Height of ridges	Rate of soil flow for drag velocity of		
		126 cm./sec.	144 cm./sec.	162 cm./sec.
	cm.		g./cm. width/sec.	
0	0	0.87	1.22	1.69
	2.5	0.17	0.36	0.64
	5.1	0.08	0.21	0.39
	10.2	0.12	0.26	0.39
	20.3	0.37	0.76	1.39
28	0	0.76	1.06	1.45
	2.5	0.10	0.20	0.35
	5.1	0.08	0.17	0.31
	10.2	0.11	0.21	0.34
	20.3	0.28	0.65	1.06

This study shows that any size ridge up to 20.3 cm. high on a cultivated soil is more effective in controlling wind erosion than is a smooth surface. However, the capacity of ridges to control wind erosion varies with their height, degree of soil cloddiness, and drag velocity.

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