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Evaluation of the Erodibility of Field Surfaces with a Portable Wind Tunnel[1]

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THE purpose of this paper is to present results obtained with the use of a portable wind tunnel in evaluating the erodibility of field surfaces to wind.

The tunnel and dust sampling equipment has been described previously (3). Operational techniques and the calibration of the tunnel to permit the control or determination of the several variables involved in field use were developed in the laboratory. These procedures also have been described (4).

Field use of the equipment and techniques was first made in November 1949. The results serve to demonstrate the possibilities and limitations of the approach. While the data at hand are limited, they throw considerable light on the interrelationships of the many factors governing the stability of field surfaces to the erosive forces of wind.

PROCEDURE

The results reported are confined to tests made on plots at the Soil Conservation Experiment Station near Amarillo, Tex. This location is approximately 500 miles from the Laboratory headquarters. The soil is a Pullman clay loam. Six field plots were selected for detailed study. The plots are approximately 10 acres in area. Several contrasting crop and cultural conditions were represented by this choice. Pertinent data concerning their use and cultural status are as follows:

Plot A-1.—Wheat stubble mulch (rotation).—Wheat-sorghum-fallow-grass rotation. During 1949 it was in wheat, following 6 years of grass. It will be seeded to sorghum in the early summer of 1950. The plot was cultivated after wheat harvest with a stubble mulch sweep machine (30 inch sweeps). Approximately 40% of the heavy wheat straw residue was standing. Wheat was combined at a height of 18 inches. Wheat drill rows are at a 14-inch spacing.

Plot A-2.—Sorghum stubble (rotation).—Wheat-sorghum-fallow-grass rotation. Cropping system consists of 18 years of wheat-sorghum-fallow, which is to be followed by 6 years of grass. Grass has not yet been seeded in the rotation. During 1949 this plot was in sorghum, with the grain combined about the first of November. The sorghum stubble is approximately 20 inches high and is left undisturbed over the winter. It is then cultivated for weed control prior to fall wheat seeding. The sorghum row spacing is 40 inches.

Plot A-3.—Wheat seeding (rotation).—Wheat-sorghum-fallow-grass rotation. Grass has not yet been incorporated in the rotation. The plot was fallowed after sorghum harvest in the fall of 1948 until wheat seeding in the fall of 1949. Wheat is drilled with a deep furrow Dempster shovel drill with 14-inch spacing.

Plot G-1-3.—Wheat seeding (continuous).—Planted continuously to wheat since 1942. The wheat is drilled with a deep furrow Dempster shovel drill with 14-inch row spacing. A one-way disk plow is used for tillage on this plot.

Plot G-1-4.—Sorghum stubble (continuous).—Planted continuously to grain sorghum since 1942. Grain was combined in the fall of 1949 at a height of about 20 inches. The plot is always left until the spring before any tillage is performed. All plantings are made with a lister in 40-inch rows. Either one-way disking or blank-listing comprises the tillage, depending on the amount of sorghum residue remaining on the plot.

Plot J-2.—Clean fallow (rotation).—This field has been in a wheat-sorghum-fallow rotation since 1944 and has been in cultivation for a long period of time. It was in sorghum in 1948 and then fallowed with a sweep machine until the time of tests in the fall of 1949. The surface was somewhat ridged from cultivation with the 30-inch sweeps.

Wind tunnel studies were made on the plots in November 1949 and were repeated in March 1950. The soil surface was in a very dry condition at the time of both series of tests. Triplicate tests, wherein the tunnel was reoriented for each test, were made on each plot in the fall of 1949. More variable conditions were encountered in the spring of 1950, and five tests were performed on each plot. The tunnel was placed over the center of sorghum rows, and tests were carried out parallel to the row direction. Tests were made at right angles to the direction of rows or cultivation on all other plots.

For a given test on a plot, the weight of soil eroded from an area 3 feet wide and 30 feet long is obtained for each of four levels of wind force. Briefly, the tunnel is first operated at a relatively low wind force level but one having a magnitude sufficient to cause measurable soil loss. This force level is maintained until soil removal ceases. The time required for stabilization of the surface varies usually within the range of 3 to 10 minutes. The eroded material is collected by the differential dust sampler at increment heights of 1, 3¼, 6 and 10 inches above the soil surface. It is then transferred to bottles for subsequent weighing and analysis. The total loss is determined by integration of the soil loss-height function by either graphical or mathematical means. The procedure is repeated subsequently for progressively increasing wind forces. The cumulative loss at each force level then permits the relation of the amount of material eroded to the level of surface drag. During the tests at each force level the pressures germane to the determination of surface drag, surface roughness, and the velocities at the four levels of dust sampling are recorded.

The size distribution of the clod structure on each plot was determined by passing samples of the surface inch of soil through a rotary sieve (2). Six samples from each plot were sieved independently to obtain representative values and a measure of the variability of clod structure.

The data obtained from the two series of tests are too voluminous to present in their entirety. The reporting of detailed results is, therefore, confined to the tests of March 1950. Differences in results for the two series of tests are brought out by discussion. A simple comparison of materials eroded from all plots for the two series of tests at an arbitrary level of wind force is made.

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C. L. Englehorn, Soil Scientist, and N. P. Woodruff, Agricultural Engineer, of the Manhattan project staff assisted the author in running the wind tunnel tests and assembling the data necessary to this report.

RESULTS

Quantity of Material Eroded from Plots

Illustrative results of the relationship between the amount of material eroded and surface drag for the several tests made on each plot are shown in Fig. 1. These data are for the March 1950 tests on continuous sorghum plot G-1-4. The amount of material eroded, x, is expressed in the equivalent of pounds per acre from the 90 square foot test area. The unit of force, τ, or the surface drag of the wind on the test area, is also given in pounds per acre. It will be noted that for a given test the material eroded is related exponentially to the surface drag of the wind. The level of the curves varies, however, for different tests.

Values of K, the ridge roughness equivalent in inches, are given for each of the curves drawn through the

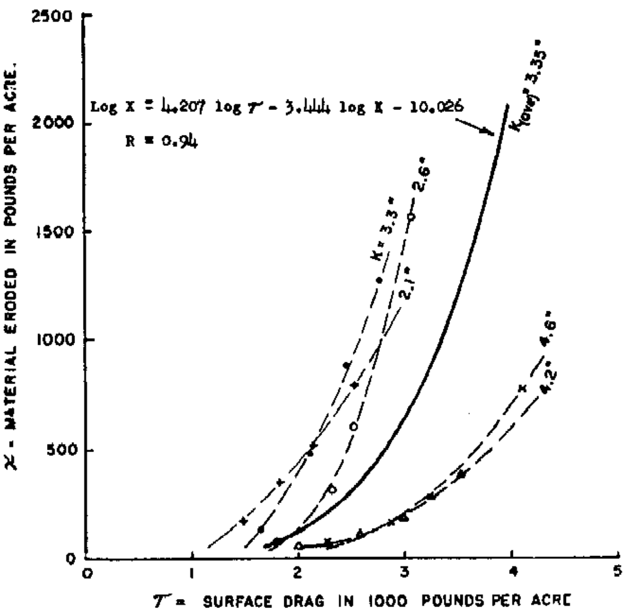

FIG. 1.—Results of five independent wind tunnel tests on continuous sorghum plot G-1-4, showing variability experienced and the average relationship derived by regression methods.

points representing separate tests in Fig. 1. The variability of K values indicates a variation in the resistance afforded to the wind by different densities of sorghum stubble. A study of the results obtained on all plots showed that individual test variability could be partially accounted for by taking into consideration the roughness of the plot surface. In general, the rougher the plot the less the amount eroded from it. This seemed to be applicable to all plots even though the roughness was widely different in nature. For example, the roughness of the sorghum stubble surface is governed primarily by the amount and orientation of stubble and residue present. The roughness of bare land is made up of surface irregularities and large clods. The effect of these contrasting surfaces is either to decrease the force of the wind on the soil or to trap the material eroding. Both types of roughness when increased in magnitude cause decreases in the amount of soil material transported to the sampling device at the end of the wind tunnel.

The apparently variable results were subjected to multiple correlation regression analysis. The approximate trend of soil loss, x, with surface drag, τ, and surface roughness, K, was assumed to be

$$x = C\tau^{a}K^{b}$$

where C is a coefficient of variation and a and b are exponents. The equation giving the best fit to the results of the five tests shown in Fig. 1 was

$$\text{Log } x = 4.207 \log \tau - 3.444 \log K - 10.026$$

where R, the index of correlation, is 0.94. Using the average value of K = 3.35 inches obtained for the five tests, the average relationship between material eroded and surface drag for the plot may be expressed as

$$\text{Log } x = 4.207 \log \tau - 11.834$$

This relationship is shown by the solid curve of Fig. 1.

The derivation of similar relationships for all plots gave values for the index of correlation ranging from 0.85 to 0.97. The percentage of the variation accounted for by the estimating equation is equal approximately to the square of this index. Thus, from 72 to 94% of the

TABLE 1.—*Clod structure of soils on plots studied with portable wind tunnel at Amarillo, Tex., March, 1950.*

Area	Stage of cropping	Clod structure by dry sieving						
		<0.42 mm	0.42–0.84 mm	0.84–2.0 mm	2.0–6.4 mm	6.4–12.8 mm	12.8–38 mm	>38 mm
		%	%	%	%	%	%	%
A-1	Wheat stubble (stubble mulch)	38.3	21.7	10.7	7.6	8.2	12.8	0.6
A-2	Sorghum stubble (rotation)	37.0	21.7	12.3	9.4	10.6	8.8	—
A-3	Wheat (rotation)	33.8	19.6	11.5	10.2	10.6	14.0	—
G-1-3	Wheat (continuous)	39.9	16.8	9.8	9.5	9.7	13.6	0.6
G-1-4	Sorghum stubble (continuous)	44.2	18.9	10.5	9.4	11.5	5.2	—
J-2	Clean fallow	35.3	12.4	10.3	12.3	12.7	17.1	0.2
	Difference between means required for significance							
5% level		2.56	1.43	0.77	0.71	0.89	3.29	*
1% level		3.44	1.92	1.04	.96	1.20	4.43	*

* No significant differences.

Note: Each percentage is the average of six determinations. Deviations from the average were the basis for differences required for various levels of significance.

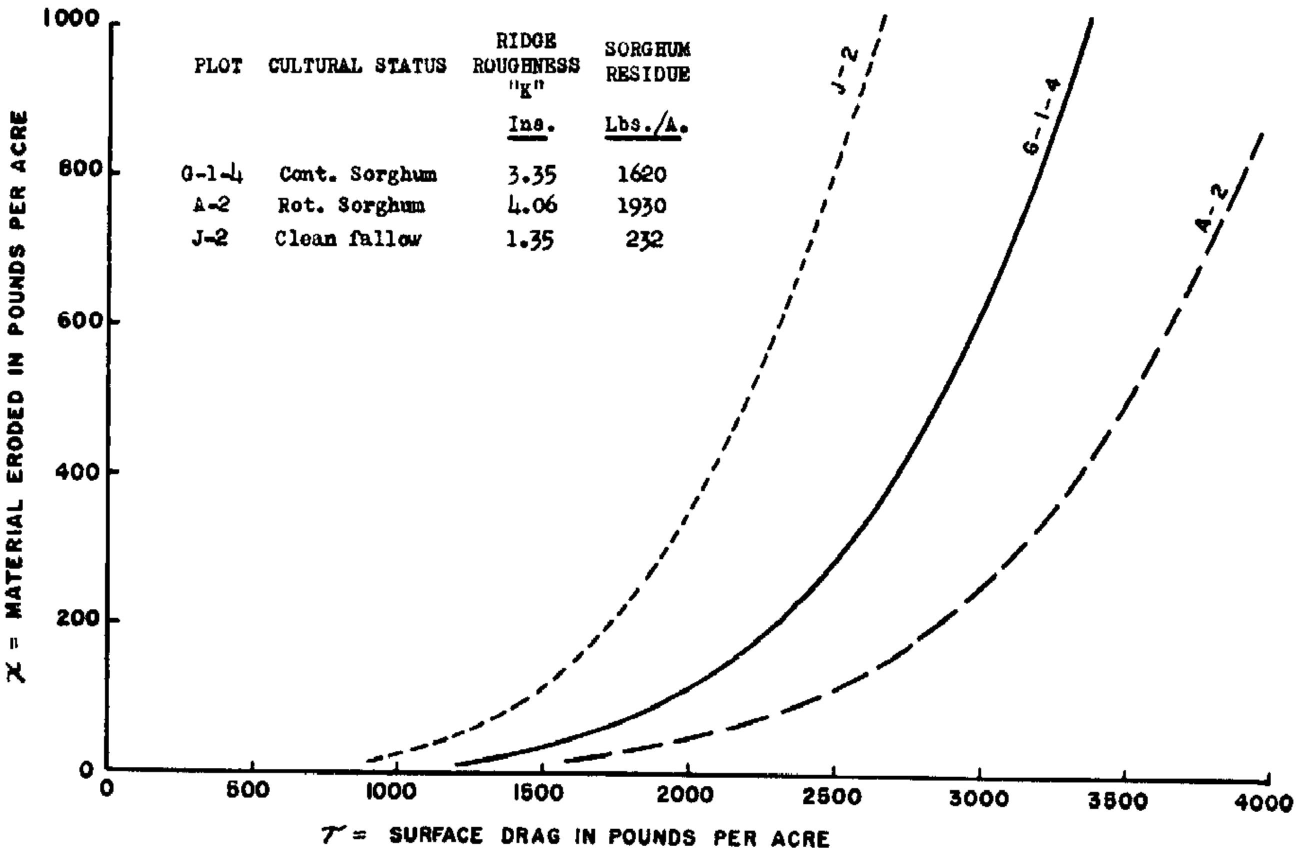

FIG. 2.—Relationship between erosion and average surface drag for G-1-4, sorghum stubble under continuous cropping to grain sorghum, and A-2, sorghum stubble in a rotation of wheat-sorghum-fallow, and J-2, a clean fallow plot.

variability of the material eroded in individual tests is accounted for by its interrelationship to surface drag, τ, and the ridge roughness equivalent, K.

Curves showing the exponential relationship of materials eroded to the surface drag of the wind for each plot studied in March 1950 are given in Figs. 2 and 3. These curves were derived by the least squares method and are plotted for average values of K. Average values of K are given for each plot.

Clod Structure of Plots

The average results of six independent dry sievings of the surface soil on each plot are given in Table 1. The differences between means for given size-fractions required for significance between plots at the 1 and 5% levels are included in the table. It will be noted that the various plots do not vary widely in clod structure. The soil from the continuous wheat plot G-1-3, however, contained more of the clod fractions < 0.42 mm than that from the rotation wheat plot A-3. In like manner, the continuous sorghum plot contained more material < 0.42 mm than did the rotated sorghum plot. It will be noted also that sorghum in the rotation produced a greater amount of small soil material than did wheat in the same rotation. All of these differences are significant at the 1% level.

Characteristics of Material Eroded from Plots

The increment dust samples collected at each height on all plots were combined for analysis. While it would be desirable to maintain a separation by plots, the samples were, in general, not of sufficient quantity for this purpose.

The eroded material retained on an 0.84 mm sieve consisted of organic matter in the form of plant and insect residues or remains. This type of material comprised approximately 2.5% of the total weight. The values obtained at four heights above the soil surface are shown in Table 3. The material < 0.84 mm in diameter was, in the main, soil material. The per cent of organic matter in this soil material as shown in Table 2 increases with height. The organic matter in the material eroded comprises about 5% of the total mass. The per cent of total material transported below given heights from the mouth of the wind tunnel is also shown in the table. Thus, approximately 20% of it moved from the 30-foot length of the tunnel below a height of 1 inch. Approximately 98% moved below a height of 1 foot.

The size distribution of eroded soil material collected at the various sampling heights above the soil surface is given in Table 3. Of interest is the fact that the proportion of material < 0.044 mm in diameter increases markedly with height, while the relative proportions of all larger fractions decrease with height. Another point

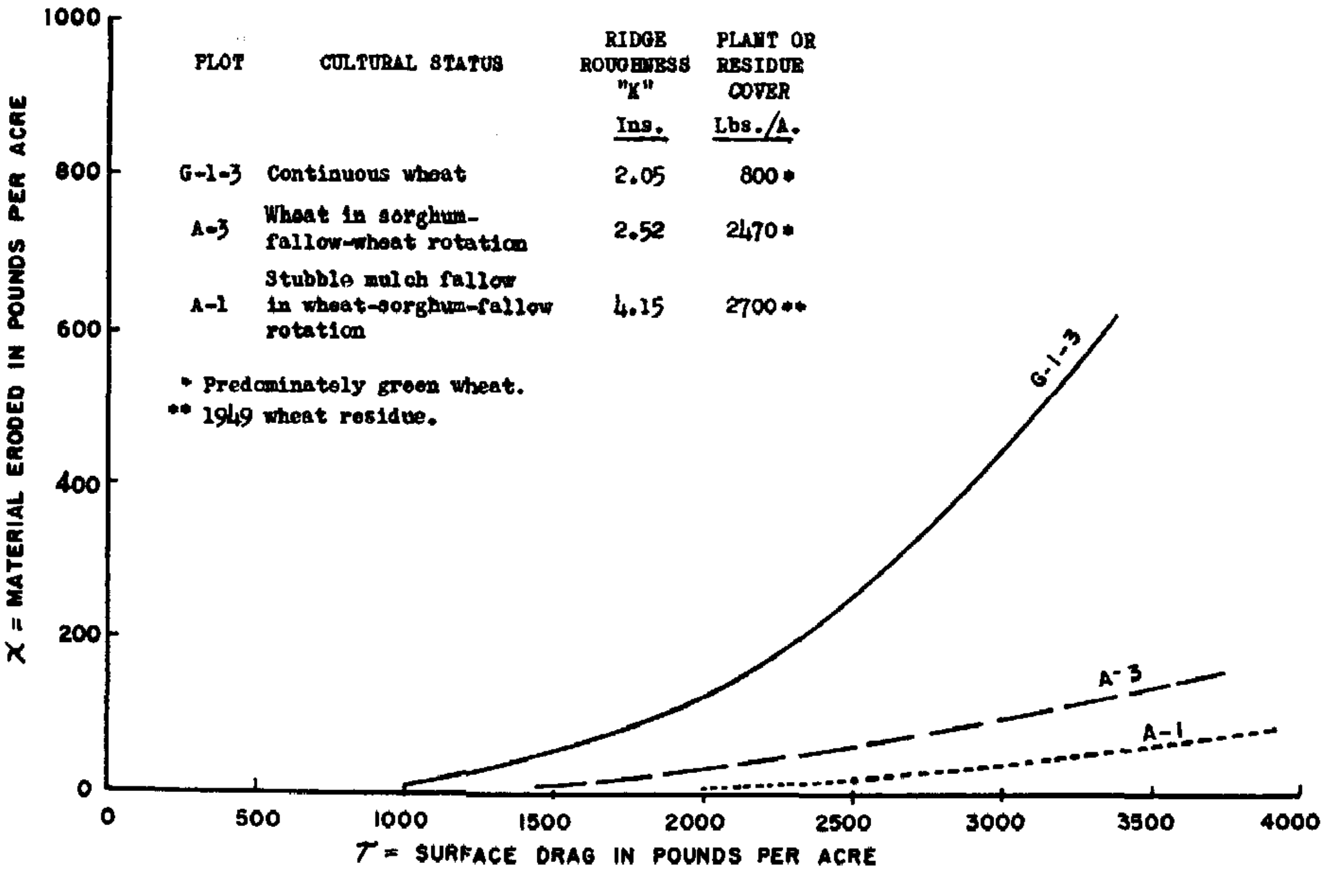

FIG. 3.—Relationship between erosion and surface drag for continuous and rotation wheat plots, and for a stubble mulched plot in a fallow condition.

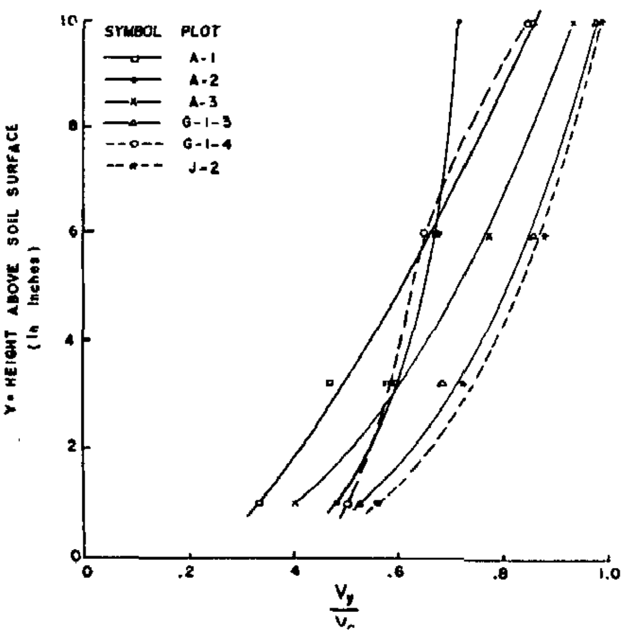

FIG. 4.—Distribution of velocities above the ground surface for plots of varying cover. The ratio $\frac{V_y}{V_c}$ is the dimensionless value of V_y, the velocity at a given height, to V_c, the velocity at an 18-inch height in the center of the duct of the wind tunnel.

of interest is that the predominant size of the eroding material is < 0.10 mm. Soil fractions below this size are capable of being sustained for a considerable time by the turbulence of atmospheric wind. In other words, they do not tend to accumulate into drifts near the fields from which they are eroded and may be transported for great distances by the wind.

WIND VELOCITY DISTRIBUTION ABOVE PLOT SURFACES

Wind velocity distributions above the ground surfaces of the various plots for the March, 1950 tests are shown in Fig. 4. These velocities were secured at four heights at the end of the tunnel in conjunction with the dust sampling procedure. They are presented on a dimensionless basis by use of the ratio $\frac{V_y}{V_c}$ where V_y is the velocity at a given height y and V_c is the velocity in the center of the 3-foot duct, i.e., a height of 18 inches.

Referring to Fig. 4, it is seen that the pattern of air flow is affected considerably by the type of cover and roughness of the plots. In general, the greater the amount of plant cover the lower is the velocity near the soil surface. Little is known of the characteristics of air flow within the height of the cover. It is apparent, however, that while the particular sorghum stubble tested is capable of making reductions at considerable heights above the ground it is comparatively ineffective in reducing the velocity near the soil surface. At the time of the tests both the stubble mulch and rotation wheat plots were superior to the sorghum stubble in this respect.

Comparison of Data Secured from Fall and Spring Tests

The land conditions on which tests were carried out in November 1949 approached an optimum, for the location, in their capacity to resist the erosive forces of wind. Rainfall had been ample to support heavy crop growth for a period of several years. The accumulation of residues was also at a near maximum for the various cultural practices. Further, the tests were made at a time when the surface on all plots tended to be hard and crusted. This condition appeared to be associated with the impact effects of abundant rainfall experienced during the spring and summer of 1949. These rains tended to puddle the soil surface. Consequently, the surface of a given plot was relatively uniform and the material eroded from the plots was mainly small particles which could be detached from the immediate surface of relatively stable clods. None of the soil material eroded from the plots in the fall exceeded 0.42 mm in diameter. The organic matter content of eroded materials was also high, comprising approximately 10% of the total weight.

Upon repeating tests on the same group of plots in March 1950 it became apparent that a considerable difference in the erodible nature of the plots had developed over the winter period. The winter was dry and free from snow. In general, the soils on the plots remained crusted, but the crust was very thin, platy, and weak. Immediately below this weak crust an aggregated soil condition was observed. Thus, when the crust was disturbed slightly by wind or other external forces, a micro-horizon of aggregated material was available for movement by wind. This condition was quite variable.

A comparison of the quantities of crop residue and growth on the plot surfaces at the time of the tests in the fall and spring is given in Table 4. Values of K, the ridge roughness equivalent, and of the per cent of the erodible proportion of the surface soil less than 0.42 mm in diameter are also given in the table.

In general, the weight of residue cover decreased during the winter period. Largest decreases were in the weights of sorghum stubble which are associated with the rapid rate of deterioration and removal by wind of the leafy portions of the plant. As the amount of residue cover decreases the value of K tends to decrease also. The wheat stubble which has been subsurface tilled has deteriorated only a small amount. Almost identical weights of green wheat and residues are shown for the fall and spring condition on Plot A-1, where wheat is grown in a rotation following fallow. It will be noted, however, that comparative values of K are 1.5 and 2.5 inches for the fall and spring conditions, respectively. While the wheat was damaged by green bugs it had grown from a 2–3 inch height in the fall to 4–6 inches in the spring, thus giving an increased roughness value. On the other hand, the continuous wheat on Plot G-1-3 deteriorated during the dry winter period and lost in both weight and roughness.

Table 2.—*Organic matter contained in material removed from plots at various heights in March, 1950.*

Height above ground surface	Organic matter		Matter transported below given heights in relation to total removal from plots
	Residues >0.84 mm	Soil material	
Inches	%*	%†	%
1	2.75	1.57	20
3¼	2.45	2.31	53
6	2.49	2.42	69
10	2.61	2.21	88
12	—	—	98‡
18	—	—	99†

* Per cent of total material eroded.
† By Walkley titration method.
‡ Estimated by extrapolation.

Table 3.—*Size distribution of material eroded at given heights, measured at the end of the 30-foot tunnel in March, 1950.*

Height above ground level	Size distribution of material eroded					
	0.84–0.42 mm	0.42–0.25 mm	0.25–0.149 mm	0.149–0.105 mm	0.105–0.044 mm	<0.044 mm
Inches	%	%	%	%	%	%
1	7.8	14.6	15.7	14.4	32.7	14.9
3¼	7.3	14.4	13.8	12.3	29.2	23.0
6	7.0	13.3	12.4	9.7	30.6	27.0
10	7.1	14.0	9.3	5.7	21.7	42.1

TABLE 4.—*Comparative amounts of plant growth and residue, values of the ridge roughness equivalent K, and proportion of clod structure < 0.42 mm in diameter at times of fall and spring tests on plots at Amarillo, Tex.*

Area	Stage of cropping	Residues and plant cover			Values of K (ridge roughness equivalent)		Soil material <0.42 mm in diameter	
		Kind	Amount					
			November 1949	March 1950	November 1949	March 1950	November 1949	March 1950
			Tons/acre	Tons/acre	Inches	Inches	%	%
A-1	Wheat stubble (stubble mulch)	Wheat stubble	1.44	1.35	3.6	4.1	24	38
A-2	Sorghum stubble (rotation)	Sorghum residue	2.74	0.97	7.1	4.1	27	37
A-3	Wheat (rotation)	Green wheat and sorghum residue	1.25	1.24	1.5	2.5	23	34
G-1-3	Wheat (continuous)	Green wheat and wheat residue	0.54	0.40	2.8	2.1	29	40
G-1-4	Sorghum stubble (continuous)	Sorghum residue	2.61	0.81	6.7	3.4	34	44
J-2	Clean fallow	Sorghum residue	0.54	0.12	1.9	1.4	26	35

The proportions of erodible soil material < 0.42 mm in diameter increased markedly on all plots during the winter period. As an average for all plots this increase was approximately 40%. The largest increase on a percentage basis occurred on the stubble mulched plot.

The material eroded-surface drag relationship determined on all plots for the fall and spring condition is amenable to varied interpretation. The basis of comparison for wind tunnel results with the performance under atmospheric wind movement has not been fully established. It is apparent, however, that an average force of wind associated with atmospheric movement is different in nature from the same average force when applied with a wind tunnel. Turbulent atmospheric wind movement is characterized by gusts of larger scale than the turbulence developed over surfaces in a tunnel. It follows that soil movement under field conditions will continue until a surface becomes stable to the relatively large forces associated with "gusts". By comparison, a surface exposed to the air stream of a wind tunnel will stabilize in a relatively short time, and a lesser quantity of soil will be removed at the same average force. Without going into details of the subject, data at hand indicate that a 30-foot length of plot of average roughness in the open would erode until it became stabilized to a wind force of approximately 3,000 pounds per acre. Such a condition would prevail at approximately 1- to 2-year recurrence intervals during the month of April. Bagnold (1) makes the assumption that the average force of the wind over surfaces in the open is governed by meteorological forces and tends, with distance, to approach a constant over surfaces of various degrees of roughness.

A comparison of material eroded from all plots in fall and spring tests on the basis of a constant surface drag of 3,000 pounds per acre is shown in Fig. 5. The values of loss are extrapolated from the curves of Figs. 2 and 3 and from similar curves derived from the fall tests. This basis of comparison is, for the present, one of expediency.

Upon referring to Fig. 5 it will be noted that two graphs for soil loss on clean fallow plot J-2 are given for November 1949, and three are given for the spring tests. While not mentioned previously to avoid confusing detail, the fallow plot was first tested in its undisturbed state and again after it had been roughened by a light disking. Disking reduced its erodibility. This was due to the fact that the operation increased the roughness of the plot and tended to bring larger clods to the surface. In March 1950 the procedure was repeated, and in addition the plot which had been disked before tests in November was exposed again to the air stream of the wind tunnel. It was found that the soil which was cultivated and gave reduced soil losses in November was more erodible in the spring than the surface which was not disturbed. Cultivating the undisturbed fallow soil immediately before tests in March again resulted in a reduction in soil loss.

Considering the losses shown in Fig. 5 it is seen that the plots were much more susceptible to erosion by wind in the spring of 1950 than they were in the fall of 1949. In general, this condition is due to decreases in residue cover and plot roughness, and to a marked increase in the proportion of soil material of the smaller erodible size. Losses from the plots in the fall of 1949 are of a low magnitude. It is of interest that erodibility was found to be in the order: clean fallow > continuous wheat > rotation wheat > continous sorghum > rotation sorghum > stubble mulch fallow. The erodibility of all plots except the one on which wheat followed fallow increased over the winter period. In the spring the order of erodibility was: clean fallow > continuous sorghum > continuous wheat > rotated sorghum > rotated wheat > stubble mulch fallow.

DISCUSSION

Results obtained in evaluating the erodibility of field surfaces with portable wind tunnel equipment indicate that the methods are adaptable to their intended purpose. In general, the results are comparable to the body of data which has been secured on a plot basis with respect to water erosion. They will be subject to like limitations in depicting the performance of practices on large areas, since factors of distance, topography, wind exposure, etc. are integral parts of the field phenomena.

Tests will have to be carried out for a period of years to cover the variations in residue or plant cover, surface roughness, and clod structure common to a given cultural practice, and to determine their interrelationship to erosion by varying wind forces. Once these data are available, it is believed a major portion of the phenomena can be accounted for and interpreted in terms of the forces common to atmospheric wind movement.

One of the weak points of the present approach is the inability to describe or gage conditions existing on the immediate surfaces of field plots. For example, when the residues are picked up and weighed we do not have a gage of their orientation on or above the soil surface. Again, when the surface inch of soil is sieved to determine the size distribution of its clod structure, the surface soil is treated as a homogeneous mass. Immediate surface conditions of the soil, including surface crusting, micro-horizons which may be either highly dispersed or aggregated, and unequal distribution of clod structure near the surface are thus ignored.

SUMMARY

This paper presents the results obtained by the use of a portable wind tunnel in evaluating the wind erodibility of plots representing various cultural practices in the high plains area.

Relationships between the surface drag of the wind and quantities of soil eroded from plots of varying soil structure, roughness, and vegetal cover are shown. The variability of results on a given plot is also shown, and factors governing this variability are cited.

Emergency cultivation, wherein the surface of fallow ground is roughened by disking, is shown to decrease the quantity of soil loss for a given wind force. Plots on which sorghum has been grown continuously are shown to be more erodible than those on which it is grown in a rotation. Land in continuous wheat is also shown to be more erodible than that where wheat follows summer fallowing. The ability of a stubble mulch to reduce the wind erosion hazard is demonstrated. The comparative erodibility of several land conditions is shown for equal wind forces.

The ability of residue and vegetal cover to change the velocity distribution of the wind near the soil surface is presented. Seasonal differences in soil structure and residue cover were measured, and their influence on erodibility is discussed.

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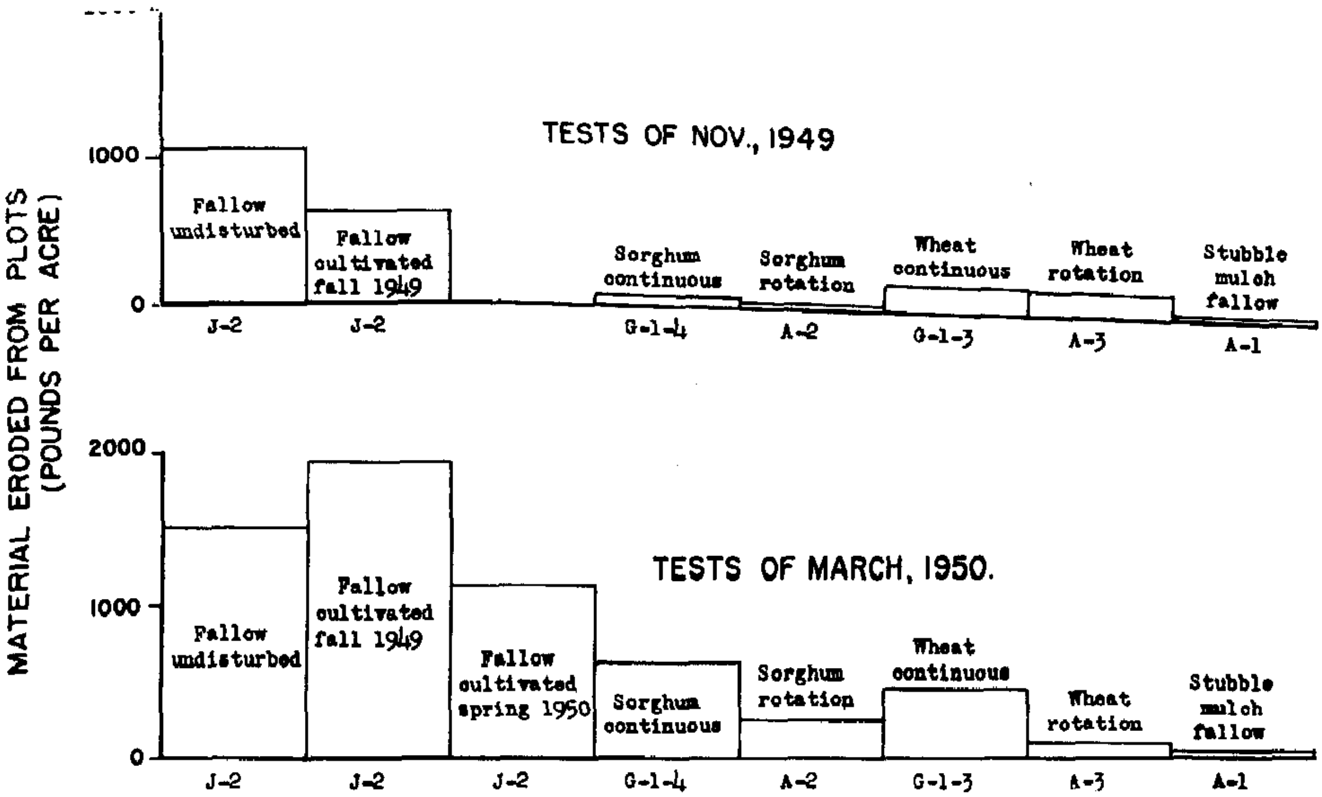

FIG. 3.—Comparison of soil material eroded from 3- by 30-foot wind tunnel test plots in the fall of 1949 and the spring of 1950 at the Soil Conservation Experiment Station, Amarillo. Tex. Comparison on the basis of a surface drag of 3,000 pounds per acre.