A Study of Wind Erosion in Northwestern Ohio

BY

N. P. Woodruff, B. L. Schmidt, E. L. Skidmore, J. D. Dickerson,

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TABLE OF CONTENTS

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Southern Plains Branch
Soil and Water Conservation Research Division
Agricultural Research Service
U. S. Department of Agriculture

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2/ Research Investigations Leader, SWC-ARS, USDA, Manhattan, Kansas; Agronomist, Ohio Agricultural Research and Development Center, Wooster, Ohio; Soil Scientist, SWC-ARS, USDA, Manhattan, Kansas; Engineering Technician, SWC-ARS, USDA, Manhattan, Kansas; Soil Scientist, SCS, USDA, Columbus, Ohio; and Conservation Agronomist, SCS, USDA, Columbus, Ohio, respectively. Acknowledgment is made to Glen E. Bernath, State Soil Conservationist, SCS, USDA, Columbus, Ohio; D. D. Smith, Assistant Director, SWC-ARS, USDA, Beltsville, Maryland; and William A. Hayes, Regional Agronomist, SCS, USDA, Lincoln, Nebraska, for their assistance in planning and organizing this study.

Introduction

Increasing damage from wind erosion has occurred in recent years on about 200,000 acres in 16 to 20 counties of northern and northwestern Ohio. The soils are sandy textured or muck. Many of the areas involved are in high-value crops such as vegetables, soybeans, and sugar beets. The reasons for increased wind erosion are believed to be due to: (a) Increased field sizes with larger areas exposed to wind, (b) removal of small farm woodlots and natural windbreaks, (c) use of larger machinery and more intensive row cropping causing more soil pulverization and fewer cover and sod crops, (d) more fall and early spring plowing exposing soil to blowing for longer periods, and (e) better weed control with modern herbicides with cleaner fence rows (9).

Field and laboratory investigations designed to gain specific information on the various factors influencing erodibility of cultivated lands in northwestern Ohio were carried out in 1967.

Personnel from the Soil Conservation Service, the Ohio Agricultural Research and Development Center, and the Agricultural Research Service participated in the investigation. The study comprised (a) analysis of climatic data, (b) erodibility tests using a portable wind tunnel from the Wind Erosion Laboratory at Manhattan, Kansas, (c) analysis of soil and residue factors related to erodibility, and (d) assessment of effects of abrasive damage on plant growth and crop yield. This report summarizes the results of investigation.

General Description of Area

The land in northwestern Ohio lies at an altitude of approximately 670 feet above sea level. The average precipitation is about 31 inches. The average annual wind velocity is about 11 m.p.h. and prevailing direction is SW from June to December and generally W-SW from January to May. Severe windstorms causing major damage to buildings occur infrequently but there are on the average 23 days per year having a sustained wind velocity of 32 m.p.h. or more.

The soils belong to the Gray-Brown Podzolic and Humic-Gley Great Soil Groups and the series studied in this investigation include Ottokee, Granby, Oakville, Colwood, Spinks, and Tedrow. The soils range from neutral to very strongly acid and from light to dark brown color. The terrain is generally level with some undulation. Drainage ranges from very poor on Tedrow to well on Oakville. Because of the level terrain and poor drainage on many of the soils, a little less than normal precipitation during crop growing seasons is better than excessive amounts. The soils are generally low in natural fertility, have low moisture-holding capacity, and are subject to wind erosion. The wind erosion problem occurs mostly under two broad soil-topography conditions, (a) on moderately well and well drained sandy soils occupying ridges, and (b) on poorly and very poorly drained soils occupying depressed areas where the surface microlayer dries sufficiently to cause excessive wind erosion.

Corn, sugar beets, tomatoes, and melons are the main crops in the area. Some fruits and berries and other vegetables are also produced on the well to excessively well drained soils.

Procedure

Analysis of Climatic Data

Wind and precipitation data from the Toledo, Ohio, airport, the closest location to the study area with complete records, were examined and plotted.

The monthly climatic factors for 24 counties in northwestern Ohio were tabulated from previously prepared climatic factor maps (7, 11).

Prevailing wind erosion directions and preponderance and magnitude of wind erosion forces for Columbus, Dayton, Toledo, Youngstown, Cincinnati, and Cleveland, Ohio, were determined and graphed from previously prepared reports (11).

Selection of Sites

Portable wind tunnel tests were run on 13 fields. Twelve of the fields were on farmers' land in Wood, Henry, and Fulton counties. The other field was on the Ohio Agricultural Experiment Station Sand Farm near Bowling Green. Sites on farmers' fields were selected to represent the different methods of preparing land for corn planting. The Sand Farm site was used to evaluate the effect of windblown sand abrasive injuries to corn, sugar beets, and tomatoes.

Soil samples were also taken from eight sites in Wood and Henry counties and sent to Manhattan, Kansas, for determination of basic wind erodibility index I' values.

The soils used in this study are described as follows:

Capability unit	Soil type	Description
IIIs855	Ottokee loamy fine sand	Associated with dune, sand knolls and ridges, or nearly level topography in lake plains; thickness of sandy material exceeds 48 inches; light-colored, acid, moderately well drained, rapid permeability, severe drouth hazard and subject to wind erosion.
IIIw938	Granby loamy fine sand	Associated with nearly level to slightly depressed areas in glacial outwash and lake plains; dark-colored, nonacid, poorly drained, severe wetness hazard.

IVs935	Oakville fine sand	Occur on outwash plains, moraines, low sand dunes, and beach ridges; slopes from 0 to 25 percent; light-colored, nonacid, well drained, severe drouth hazard and subject to wind erosion.
IIw608	Colwood silt loam	Occur on nearly level depressional areas on outwash and lake plains; slopes from 0 to 2 percent; dark-colored, nonacid, poorly drained, moderate wetness hazard.
IIIs855	Spinks loamy fine sand	Occur on gently undulating or sloping till or outwash plains; light-colored, acid, moderately well drained, severe drouth hazard and subject to wind erosion.
IIw922	Tedrow loamy sand	Occur on low dunes and ridges or nearly level areas in lake plains; light-colored, acid, somewhat poorly drained, moderate wetness hazard.

Portable Wind Tunnel Tests

Triplicate wind tunnel tests were made on each site and a total of 84 separate tests, 42 on farmers' fields and 42 on the Sand Farm plots, were conducted during the period May 22-26, 1967. Most of the tests were run with wind applied perpendicular to row direction; however, both perpendicular and parallel to row tests were conducted on two of the farmers' fields and on the corn and tomato plots on the Sand Farm. Wind velocity through the center of the tunnel was approximately 38 m.p.h. On slightly and moderately erodible fields the wind was applied until erosion ceased. Four minutes was required for the surface to stabilize. On highly erodible fields, weight of soil removal at the end of three successive time periods (3, 6, and 9 minutes) was determined and the total amount of erosion was then estimated from extrapolation of the trend line of soil loss with time.

When wind velocity in the center of the tunnel duct is held constant, the wind force applied to the test surfaces varies with roughness. Soil loss before a surface becomes stabilized varies with surface drag to the 2.5 power (8). This power function of soil loss with surface drag was used to adjust all losses to a common wind force level of 3,000 pounds per acre which is equal to the drag exerted by a wind of about 85 m.p.h. measured at the 50-foot elevation blowing over a relatively smooth field with a roughness Z_0 of 0.005 foot.

An aerodynamic roughness of test surfaces expressed in terms of "ridge roughness equivalent" was determined from pressure relationships measured in the tunnel (13). The "ridge roughness equivalent" K' in the wind erosion equation (12) is an equivalent roughness based on the height of ridges composed of fine gravel 2 to 6.4 mm. in diameter and having a height-spacing ratio of 1:4. Its value depends on many factors such as height, length, density, quality of vegetative cover, and the size and shape of clods, ripples, and ridges. Ridge roughness was also estimated by making a linear measurement of roughness to obtain a factor

$$K_r = \frac{\text{Standard ratio (1:4)}}{\text{Field measured ratio (1:X)}} \times \text{(Ridge height)}$$

which was then converted to K' from charts included with the wind erosion equation (12) and used in the equation to compare soil losses as determined with the tunnel with those calculated from the wind erosion equation.

Semiportable Wind Tunnel Tests

In addition to its use on field tests, the portable wind tunnel was used at the Manhattan, Kansas, headquarters to determine the basic wind erodibility I' for representative soils from eight sites in northwestern Ohio. The relative wind tunnel erodibility index $I_W = 10\ X_2/X_1$, in which X_1 is the quantity eroded when the soil contains 60 percent by weight of clods greater than 0.84 mm. and X_2 is the quantity eroded under the same set of conditions from soil containing any other proportion of clods greater than 0.84 mm., was determined by placing the soils in 5-foot-long by 0.5-foot-wide trays and exposing them to a drag velocity of 61 cm. per second in the wind tunnel. The relative field erodibility or soil erodibility I' used in the wind erosion equation was then computed from the relationship

$$I' = 1/3\left[140 I_W^{0.287} - \frac{1}{(0.01525)(1.065)^{I_W}}\right] \qquad (1)$$

Detailed theory and background for determination of erodibility I' is given in a previous publication (2).

Soil and Residue Sampling

Soil and residue samples were obtained for each wind tunnel test during the wind tunnel runs. General procedures were as follows:

(a) Crop residue weight.--Crop residues on the soil surface were collected from a 1-square-meter quadrant, bagged, washed, ovendried, and weighed.

(b) Soil moisture content.--From 8 to 10 subsamples of the surface half-inch of soil were collected randomly adjacent to each wind tunnel site. The samples were mixed and the moisture content determined gravimetrically.

(c) Nonerodible soil fraction.--Random subsamples of the surface inch were collected with a flat pan at each wind tunnel run site. A 4-pound subsample was weighed and placed in an 0.84 mm. rotary sieve. The sieve was turned at the rate of one rotation per 2.5 seconds for five total revolutions. Material remaining in the sieve was weighed and reported as the percent nonerodible fraction.

Composite soil samples of about 150 pounds were taken under air-dry conditions to a depth of 1 inch from each of the eight sites used to determine erodibility index I'. The samples were placed in large wooden trays to prevent pulverization and were transported to Manhattan. Each sample was split into three parts. Two parts were used to provide material for running replicated wind tunnel tests and the third part was used to determine size distribution of dry aggregates or clods with an automatic rotary sieve used regularly in this work (1).

Plant Growth and Crop Yield Data

Some plant growth and crop yield data were obtained from the wind tunnel sites on the Jones and Sand farms. The Jones farm sites were layed out in 66-foot north-south strips. Corn was planted on May 4, 1967, in 40-inch rows. The no-tillage planter was used on the untilled land. The conventional planter and the "sidewinder" till planter were used on the strip-tillage areas. Yield samples were taken on October 24, 1967, by hand-harvesting the corn on each wind tunnel site and on an adjacent check site on each tillage treatment on the Spinks soil.

The Sand Farm plots were 7 feet wide and ranged in length from 30 to 84 feet. Sugar beets were planted in 40-inch rows with a 4-row planter with beet attachment. Corn was planted with a conventional 4-row planter in both tilled and no-tillage areas in 40-inch rows at a population of 24,000 seeds per acre. Tomatoes (Heinz 2198) had been transplanted into 5-foot rows with 1-foot spacing between plants on May 18 but a strong wind on May 20 ruined these plants. New tomato plants were planted just prior to the tunnel runs but these plants were quite wilted at the time of the tests. Plant height measurements were made on the corn plots immediately after the tunnel tests and at 2 and 6 weeks after the runs. Yields were measured on September 26, 1967, on the corn plots which had been subjected to parallel-to-row tunnel tests by hand-harvesting the 30 feet of row covered by the tunnel. An adjacent row was harvested as a check. Since tomato plants varied greatly in height, only survival counts were made immediately after tunnel runs and 2 weeks later. No tomato yield or sugar beet survival or yield was taken.

Results

Precipitation and Wind Movement

Figure 1 shows average and 1967 rainfall and wind movement for Toledo, Ohio, the closest weather station to the study with complete records. The high wind movement for November through April when many fields are bare, freezing and thawing occurs, and rainfall from November through February is low makes this period the most critical for wind erosion.

Wind movement for 1967 was below the 78-year average. While conclusions cannot be drawn from 1 year's data, this lower velocity during 1967 would seem to dispute the popular opinion that removal of woodlands and other natural obstacles to wind has resulted in higher wind velocities in recent years.

Monthly Climatic Factors

Table 1 shows monthly climatic factors for 24 counties in northwestern Ohio. These factors are very low compared to the Great Plains and other more arid regions. This can be interpreted as indicating that the area has a very low potential wind erosion hazard which would be expected where precipitation is fairly uniformly distributed throughout the year and averages about 31 inches annually. The wind erosion that does occur in northwestern Ohio results from (a) many of the soils being extremely sandy and the microlayer on top drying quickly, (b) many fields located on knolls where they are subjected to maximum wind shear stresses, and (c) the nature of crops grown and tillage methods used which leave the

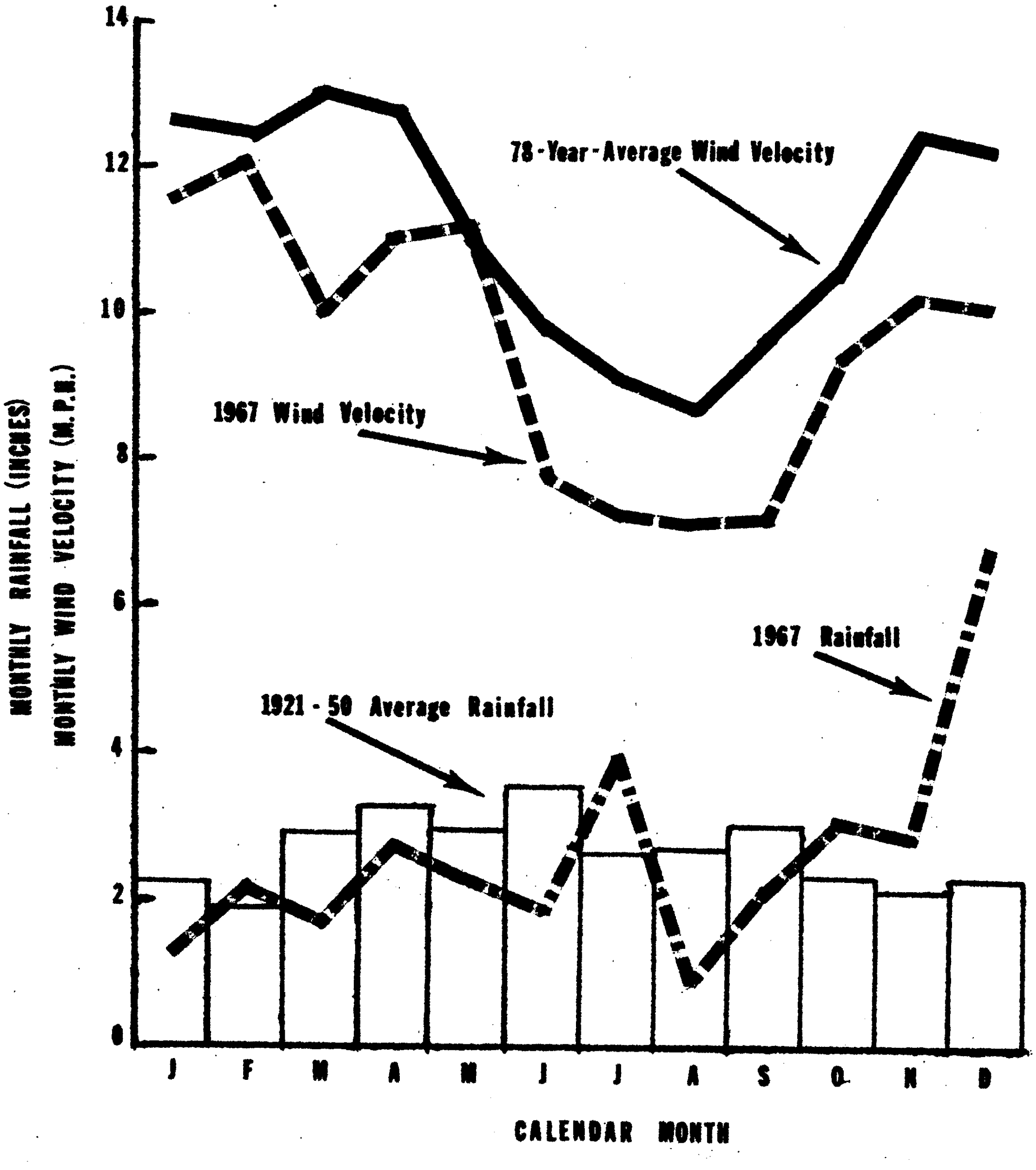

Figure 1.--Average and 1967 rainfall and wind movement by calendar months at Toledo, Ohio. Average rainfall is based on period 1921-50. Average wind movement is based on 78-year period ending 1958.

Table 1.--Monthly climatic factors C' for 24 counties in northwestern Ohio.

County	Monthly value of C'											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Williams	8	10	10	10	5	5	3	2	4	5	8	8
Defiance	8	10	10	10	5	5	3	2	4	5	8	8
Paulding	8	10	10	10	5	5	3	2	3	5	8	8
Van Wert	8	8	9	9	5	4	3	2	3	5	7	7
Fulton	10	10	10	10	5	5	3	3	4	5	9	9
Henry	9	10	10	10	6	5	3	3	4	5	9	9
Putnam	9	10	10	8	5	5	3	3	4	5	8	8
Allen	8	9	9	8	5	5	3	3	3	4	7	7
Lucas	10	10	12	12	7	5	3	3	5	5	9	10
Wood	10	10	12	12	7	5	3	3	5	5	9	10
Hancock	9	10	10	10	5	5	3	3	4	5	8	6
Hardin	8	10	8	8	4	4	2	2	3	4	6	5
Ottawa	10	10	12	12	7	5	3	4	5	5	9	10
Sandusky	9	10	10	10	6	5	3	4	4	5	8	8
Seneca	8	10	9	7	5	4	3	3	3	5	7	6
Wyandot	8	8	8	7	4	4	3	2	3	5	6	5
Marion	7	7	8	7	4	3	2	2	3	4	5	5
Crawford	7	8	8	7	4	3	2	2	3	5	6	5
Erie	8	9	10	7	5	5	3	3	4	5	8	8
Huron	7	8	9	7	5	4	3	3	4	5	7	7
Richland	7	7	8	6	3	3	2	2	3	4	5	5
Lorain	9	8	9	7	6	4	3	3	4	5	8	8
Ashland	7	7	8	6	4	3	2	2	3	4	6	5
Morrow	6	7	7	6	3	3	2	2	2	4	5	5

fields bare and vulnerable during times of the year when wind velocities are highest.

The highest values of the monthly climatic factors (10 to 12) occur in the period from December through April and this is the period for which wind erosion control practices should be designed.

Prevailing Wind Erosion Direction

Figure 2 shows direction, magnitude, and preponderance of wind erosion forces at six locations in Ohio. It is apparent that the magnitude of wind erosion forces, which is the sum of the magnitudes of wind erosion force vectors for all directions and indicates the relative capacity of the wind to cause soil blowing, is two to three times greater for the Toledo area than for other locations. Also, the magnitude for Toledo is greatest for the months of November through April with March being exceptionally high.

The direction arrows for Toledo on figure 2 show that the winds during the period November through April are from a W-SW to SW direction and the ratios for parallel to perpendicular winds are sufficiently large to indicate that barriers would be most effective in the area if oriented at right angles to the direction arrows or in a NW-SE direction.

Wind Erodibility I'

Figure 3 and table 2 show the results of the semiportable tunnel tests to determine wind erodibility I' for representative northwestern Ohio soils. Figure 3 indicates that the Ohio soils are potentially more erodible than the Great Plains soils and therefore table 2 of this report

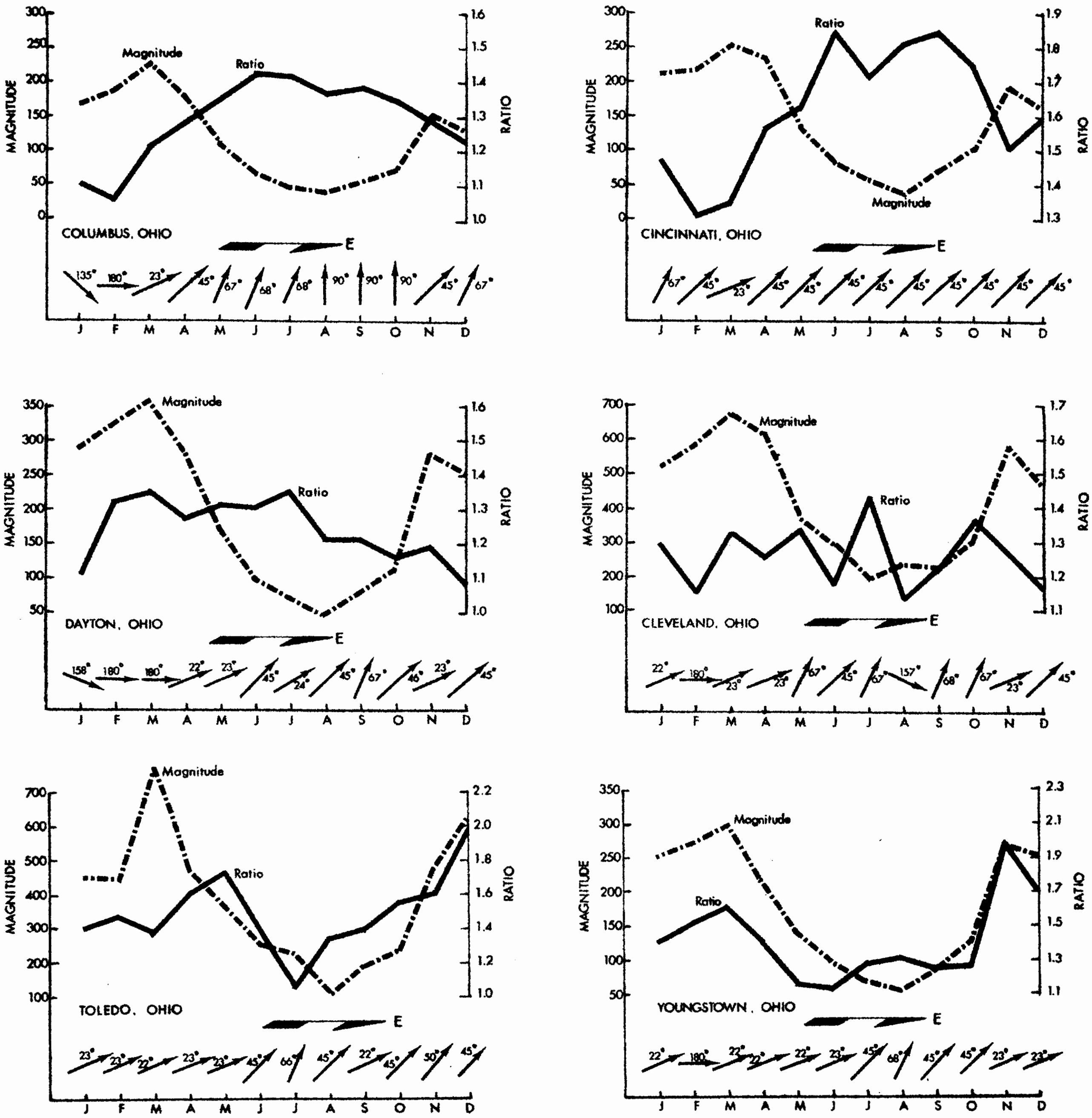

Figure 2.--Direction, magnitude, and preponderance (ratio) of wind erosion forces at six locations in Ohio. Arrows indicate predominant direction of winds. The magnitude of wind erosion forces indicates the relative capacity of the wind to cause soil blowing. Preponderance is a measure of the prevalence in the wind erosion direction and the larger the ratio the greater the prevalence.

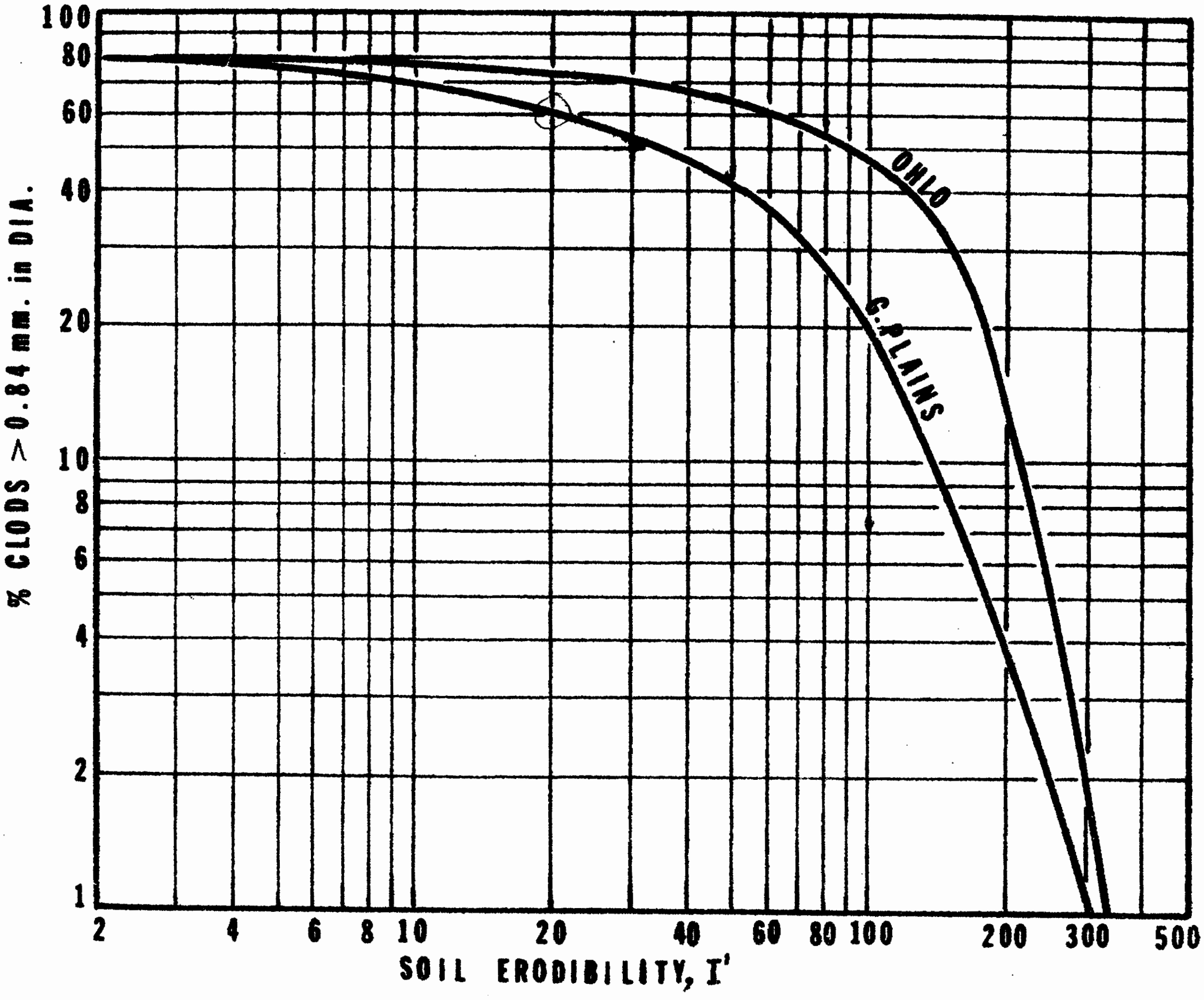

Figure 3.--Comparison of soil erodibility I' for Ohio and Great Plains soils.

should be used rather than table 1 of the wind erosion equation publication (12) when applying the equation to Ohio conditions. The importance of this can be seen if field length and residue conditions are assumed and the equation is applied to two of the Ohio sites that were sampled.

Table 2.--Soil erodibility I' for Ohio for soils with different percentages of nonerodible fractions as determined by standard dry sieving.

Percentage of dry soil fractions > 0.84 mm. Units ⟶ Tens ↓	0	1	2	3	4	5	6	7	8	9
					Tons/A.					
0	---	340	295	270	255	242	232	225	220	215
10	210	205	200	197	194	190	187	184	182	180
20	178	175	172	170	168	165	163	161	159	156
30	154	152	150	148	145	142	140	137	134	130
40	128	125	122	118	115	112	109	105	102	98
50	95	91	89	86	83	78	76	73	68	65
60	61	57	53	49	45	42	39	35	32	30
70	26	24	22	19	16	14	12	9	7	5
80	2	---	---	---	---	---	---	---	---	---

Wood site 5.--Table 2 of this report indicates an I' value of 304 for the 1.8 percent fractions greater than 0.84 mm. in diameter in this soil but table 1 of the wind erosion equation publication (12) indicates an I' value of 262 for this same cloddiness condition. If we assumed a field with an L' equal to 1/4 mile, a K' equal to 1.0, and 700 pounds per acre of residue and calculated E with the equation using a C' of 10 for northwestern Ohio, we would get 13 tons per acre with an I' value of

304 and only 10 tons per acre with an I' value of 262. Use of I' values from the Great Plains table would therefore cause us to underestimate the potential soil loss by about 23 percent. Conversely, if we used the equation to determine the amount of residue or width of strip needed to reduce soil loss to a tolerable amount of 1.0 ton per acre, we would calculate 100 pounds per acre short on the residue needed and 7 feet too wide on width of strip.

Green Springs 1.--Table 2 of this report indicates an I' value of 140 for the 36 percent fractions greater than 0.84 mm. in diameter in this soil but table 1 of the wind erosion equation publication (12) indicates an I' value of 63 for this cloddiness condition. Again, if we assume the same field size, roughness, residue, and climatic condition as for Wood site 5 and calculate soil loss with the equation, we get 5.0 tons per acre with an I' value of 140 and only 1.4 tons per acre with an I' value of 63, or using Great Plains I' values, underestimate soil loss by about 72 percent. Conversely, if we used the equation to determine amount of residue or width of strip needed to reduce soil loss to a tolerable amount of 1.0 ton per acre, we would calculate 300 pounds per acre short on residue and about 800 feet too wide on width of strip. Thus, even though the potential erosiveness of this site is considerably lower than on Wood site 5, the errors that could be caused by applying the Great Plains I' values to Ohio are extremely large.

In conclusion, it seems quite apparent that the Ohio soils are potentially more erosive than Great Plains soils and it is advisable to use I' values determined from Ohio soils (table 2) when applying the wind erosion equation to Ohio conditions.

Erosion from Farmers' Fields

Measured soil losses.--Photographs of conditions of each of the 12 sites on farmers' fields on which 42 wind tunnel tests were conducted are shown on Appendix pages 37 to 48. A summary of information relative to location, cropping, soil characteristics, and amount of soil eroded in the portable tunnel is given for each site. Complete information for each of the 42 tunnel tests is given in Appendix Table 1, page 49.

Conditions for wind tunnel testing were not ideal in Ohio in May 1967. A cool, wet spring had delayed crop growth and many of the soils were not dry enough to be in a highly erodible condition. Average soil losses from the farmers' fields ranged from zero to 181 tons per acre with one of the individual replicates on the Ottokee loamy fine sands on plowed corn ground going as high as 386 tons per acre.

The wind tunnel soil loss data indicate that plowing and disking for corn is a poor practice in northwestern Ohio from the standpoint of controlling wind erosion. Soil losses from land prepared in this manner were many times greater than losses from untilled cornland or from land which had been prepared with the sidewinder or power disk. It is also evident from tests on plowed, disked, and planted cornland on the Jones, Westhoven, and Chambers farms that Spinks and Ottokee loamy fine sands are far more susceptible to wind erosion than the Oakville fine sands, the Tedrow loamy sands, the Colwood silt loams, or the Granby loamy fine sands. Effects of wind direction relative to row direction are shown by comparison of results from parallel and perpendicular tests on Ottokee and Granby soils on the Westhoven farm. Tunnel losses from both the Ottokee and Granby soils are approximately three times greater with winds parallel to row than from winds perpendicular to the row.

Measured soil losses in relation to surface variables.--Data from the 42 wind tunnel tests on farmers' fields were used to examine relationships between the dependent variable soil loss and the independent variables: residue, surface roughness, surface soil moisture, and soil cloddiness. The IBM 360 Computer was used to develop several linear and curvilinear equations by multiple regression. The data was analyzed in original arithmetic form to derive a linear relationship, with complete logarithmic transformation to derive curvilinear power functions, and with partial logarithmic transformation to derive a curvilinear exponential function.

The linear relationship derived accounted for only about 20 percent of the variability in the data and therefore was not reliable enough for use in predicting effects of independent variables.

The relationship derived after complete logarithmic transformation was much better than the linear relationship and accounted for about 85 percent of the variability. However, this analysis indicated a very high intercorrelation between clods with soil moisture and residue with roughness and therefore the contribution of individual variables was somewhat dependent upon the order in which they were considered in the regression. If the computer was programmed to add variables in a stepwise manner by contribution to sum of squares, then clods and residue were considered first and they accounted for nearly all the variability with essentially no contribution from roughness and soil moisture. However, if soil moisture and roughness were considered first, then there was a smaller but more equal contribution from each of the four variables.

The relationship derived with partial logarithmic transformation--the dependent variable soil loss only--and arithmetic values of the independent variables accounted for about 79 percent of the variability so this relationship was considerably better than the linear but not quite so good as that obtained with complete logarithmic transformation.

Since there was a strong intercorrelation between surface roughness and residue, a fourth relationship was derived using logarithmic transformations on soil moisture, cloddiness, soil loss, and the product of residue times roughness. The relationship derived was

$$E = 17{,}220 \frac{M^{0.029}}{A^{2.236}(RK)^{0.746}} \tag{2}$$

where E = wind tunnel soil loss in tons per acre

A = percent surface clods greater than 0.84 mm. in diameter

K = surface roughness in equivalent inches

M = percent moisture in surface soil

R = residue on surface in pounds per acre.

With the computer adding variables stepwise by contribution to sum of squares, the results were:

Variable	Contribution to R^2
A - clods	0.3766
RK - residue x roughness	0.4692
M - moisture	0
Total R^2 =	0.8458

Equation 2 and the other three derived equations all indicated a direct, positive relationship between soil loss and soil moisture and also that soil moisture makes a very small contribution to R^2, especially when cloddiness is considered first in the regression. It is very difficult to accept this as being real and it is also difficult to understand the high intercorrelation between soil moisture and cloddiness. Soil loss should not increase as soil moisture increases and it would seem that soil moisture should have more effect on soil loss than the R^2 indicates. Apparently the strong correlation between cloddiness and soil moisture is due to the particular conditions of these tests. Many of the fields with the higher percentage of aggregates greater than 0.84 mm. in diameter had been freshly tilled and since the soils were relatively wet before tillage, it follows that the surface clods were probably also higher in moisture than normally would be expected in surface clods. There is a definite need for further study of the role of surface soil moisture on wind erodibility.

The high value of the intercorrelation between residue and roughness is understandable because the wind tunnel determines roughness by measuring its effect on resistance to windflow in terms of a pressure drop in the tunnel duct and it is therefore unable to tell the difference between residue and soil ridges. Other wind tunnel data has also indicated a close relationship between R and K (4, 5, 6).

Since soil moisture contributes very little to the regression and there is some question about the validity of the relationship between soil moisture and soil loss determined from this study, it is recommended that soil moisture be dropped from the estimating equation. It is also recommended that the product RK be used rather than considering each variable individually. The estimating equation then becomes

$$E = \frac{16,150}{A^{2.21}(RK)^{0.74}} \qquad (3)$$

R^2 for this relationship was 0.8458.

This equation accounts for approximately 85 percent of the variability in the data and could be used for estimating wind tunnel erodibility of fields in Ohio if measurements of cloddiness, residue, and roughness were available. Some idea of the accuracy that could be expected from such estimates may be obtained from the degree of deviation of individual measurements of erodibility shown in figure 4. It is apparent that the estimating equation would tend to underestimate both very low and very high erosive conditions but would do rather well in predicting erosiveness of the intermediate conditions.

Comparison of measured soil losses with losses calculated from the wind erosion equation.--Table 3 presents a summary of average data from the three replications of the wind tunnel tests on each of the 14 different fields. The last two columns are shown to give some rough idea of how soil losses obtained with the wind tunnel compare with those one might calculate with the wind erosion equation, $E = f(I',K',C',L',V)$.

Good data for making these comparisons are not available and there is a very definite need for more measurements of natural wind erosion in northwestern Ohio. The wind tunnel determines the erodibility of a particular field for the particular wind velocity or shear stress applied at the particular field condition tested. This erodibility is expressed in tons per acre. The wind erosion equation also determines the erodibility of the field for the particular field conditions but it expresses the erodibility in terms of tons per acre per year. In other words, the equation expresses an annual loss that could be expected from a field located in the particular climatic area with the cloddiness, residue, and roughness conditions measured. Interpretation of wind tunnel data in terms of annual

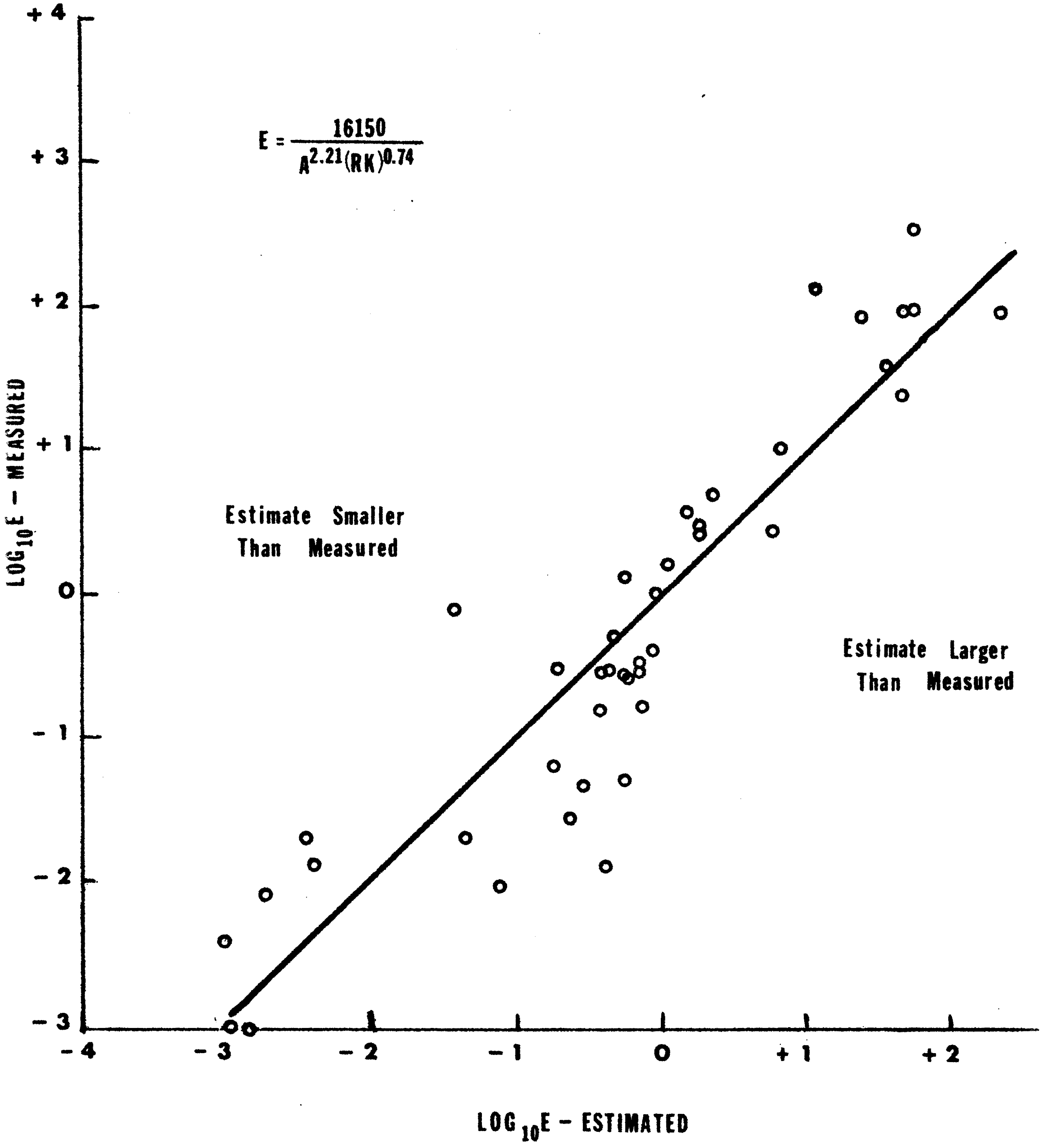

Figure 4.--Correlation between measured and calculated erodibility.

Table 3.--Comparison of measured soil losses with losses estimated from the wind erosion equation on farmers' fields in northwestern Ohio.

Name of farm	Surface condition and soil type	Residue	Soil fractions > 0.84 mm. in diameter	Roughness K_r	Soil loss: Wind tunnel: Measured	Soil loss: Wind tunnel: Adjusted1/	Soil loss: Calculated from equation2/
		Lbs./A.	Percent	Inches	Tons/A.	Tons/A./Yr.	Tons/A./Yr.
		-- Wind perpendicular to row --					
	Plowed, disked, and planted						
Jones	Spinks, lfs	0	4.9	0.8	106.9	21.7	13.5
Westhoven	Ottokee, lfs	0	6.5	1.8	55.9	9.6	7.2
Westhoven	Granby, lfs	0	38.0	2.4	0.7	0.08	3.0
Jones	Colwood, fsl	0	52.6	1.9	0.2	0.01	1.8
	Sidewinder and planted						
Jones	Spinks, lfs	2,088	5.2	1.4	0.6	7.0	4.0
Jones	Colwood, fsl	2,419	64.6	0.9	0	0	0.3
	Untilled cornland, planted						
Jones	Spinks, lfs	3,457	7.5	1.1	0.1	0.7	0.8
Westhoven	Oakville, lfs	5,363	11.2	0.7	0.7	3.4	0.1
Jones	Colwood, fsl	3,200	82.3	0.5	0	0	0
	Plowed						
Chambers	Tedrow, lfs	0	42.7	1.1	0.2	0.01	3.5
	Plowed and raked						
Chambers	Tedrow, lfs	0	51.5	0.2	0.3	0.02	4.0
	Power disked						
Westhoven	Oakville, lfs	1,371	4.4	0	3.4	10.8	17.0
		---- Wind parallel to row ----					
	Plowed, disked, and planted						
Westhoven	Ottokee, lfs	0	10.6	0*	181.1	41.5	19.0
Westhoven	Granby, lfs	0	25.0	0*	3.2	9.6	14.0

1/ Adjusted to 40-rod field length according to previous publication (3) and based on natural erosion measured in cans on Jones farm by Schmidt.

2/ Based on field length of 40 rods and climatic factor C' = 10 percent.

* Assumed roughness K_r parallel to row.

soil loss requires some information on natural erosion. Annual losses expressed by the wind erosion equation are based on a comparison of natural losses from a large number of fields in the Great Plains during 1954-56 with wind tunnel losses from these same fields. The climatic factor for the Great Plains is about 100. The climatic factor for Ohio is about 10. Therefore, it is not reasonable to adjust Ohio wind tunnel losses to annual losses on a basis of Great Plains data. The only natural erosion measurements available from the same fields on which tunnel measurements were made in Ohio are those by Schmidt on the Jones farm on the plowed and untilled Spinks loamy fine sands. Natural losses were determined by burying 6-inch-diameter cans in the 66-foot-wide test strips. Measured losses were 1.225 and 0.216 tons per acre per month on plowed and untilled cornstalks, respectively. Assuming this type of catcher traps only the surface creep coming from a strip 0.5 foot wide and 72 feet long (72 feet because the prevailing wind crosses the field at a 23 degree angle from perpendicular), that surface creep comprises only about one-fourth of the total soil loss (14), and that the Ohio soils are susceptible to wind erosion only 5 months of the year, then the annual soil loss amounts to 24.5 tons per acre on the plowed land and 4.3 tons per acre on the untilled cornstalk land. Wind tunnel losses on these two fields were 106.9 tons per acre on the plowed land with no residue and 0.1 ton per acre on the untilled land with 3,457 pounds per acre of residue. The adjusted annual wind tunnel losses for plowed land shown in the second from last column of table 3 were obtained by first converting wind tunnel losses to 40 rod field length losses according to procedures described by Chepil (3) and then multiplying these losses by the factor 24.5/106.9 = 0.229. The same procedure was also applied to the untilled cornland on the Spinks soils except that a factor 4.3/0.10 = 43 was used. Losses for fields with amounts of residue different than zero or 3,457 pounds per acre were corrected for field length, then adjusted by a variable factor obtained by assuming a $y = ax^n$ relationship between correction factor and amount of residue which passed through the data points (R = 0, Factor = 0.229) and (R = 3,457, Factor = 43).

A climatic factor C' of 10 percent was used in calculating soil losses with the wind erosion equation. The measured K_r values were converted to K' values by using figure 4 of the publication by Woodruff and Siddoway (12). I' values corresponding to the measured soil fractions were taken from table 2 of this report. Field length L' was taken to be 40 rods.

A comparison of the last two columns of table 3 indicates that close agreement is obtained between the two methods of determining soil loss on only two of the cases; however, reasonable agreement is obtained on about half the sites. Generally, agreement is best on sites having high wind tunnel erodibility and poorest on sites with residues or low tunnel erodibility. The wind erosion equation seriously underestimates erodibility on only about 2 out of the 14 sites.

Because of the limited natural erosion data available and the many assumptions necessary for its use and the possibilities for error in determining K_r and soil cloddiness, these can only be considered very rough comparisons. There is a very definite need for more data and study, particularly in obtaining some better idea of natural erosion. However, since there is some indication of agreement and since the wind erosion equation only underestimated on about 15 percent of the cases, it is believed that it can be used with judgment in designing wind erosion control practices in northwestern Ohio.

Corn yields, Jones farm.--Yield and stand samples made in October 1967 on the Jones farm on the plowed, untilled, and sidewinder tilled wind tunnel sites and on adjacent check sites are summarized in table 4. Mean corn yields under both sidewinder tillage and no tillage appear to be higher than on plowed soil on the wind tunnel plots on the highly erosive Spinks soil. Mean yields on the check plots showed an advantage for sidewinder tillage and were higher than on the wind tunnel plots except with no tillage. Yields and plant population followed the same trends in most cases.

Table 4.--Mean corn yields and stands on wind tunnel and check sites on Spinks soils on Jones farm.

Tillage method	Wind tunnel soil loss	Mean yields		Mean stands	
		Wind tunnel site	Check	Wind tunnel site	Check
	Tons/A.	Bu./A.	Bu./A.	Thousand plants/A.	
No tillage	0.1	59.3	54.7	16.6	15.8
Plow	55.9	47.3	51.8	15.0	18.5
Sidewinder	0.6	61.7	71.5	15.6	16.4

Erosion Tests on the Sand Farm

Measured rates of sand drift.--Photographs of conditions of the corn and sugar beets on plowed and untilled plots and the tomatoes on plowed plots at the Sand Farm on which 42 wind tunnel tests were run to evaluate abrasive injuries to plants are shown on Appendix pages 50 to 54. A summary of information relative to location, crop, soil characteristics, amount of residue, roughness of surface, rate of sand drift, and plant height and yield where measured is given for each plot. Complete information for each of the 42 tunnel tests is given in Appendix Table 2, page 55.

Because of moist soil conditions and natural wind erosion prior to the tunnel tests, rates of sand drift were extremely low in all of these tests and this, coupled with the very small size of the plants at test time, resulted in little plant damage and inconclusive results. Rates of sand drift obtained in the tunnel ranged from 0.001 to 0.046 ton per rod per hour which is considerably lower than the 0.2 to 0.6 ton per rod per hour known to be required to cause substantial injury to vegetables and used in laboratory studies of abrasive damage to vegetables (10).

Measured rates of sand drift in relation to surface variables.--Data obtained from the 42 wind tunnel tests on the Sand Farm were also used to examine relationships between the dependent variable, rate of sand drift, and the independent variables: surface roughness, surface soil moisture, and soil cloddiness. The data were analyzed in original form to derive a linear relationship and with complete logarithmic transformation to derive curvilinear relationships.

The linear relationship derived was

$$E_R = 74.90 - 2.977A - 0.019R - 8.458K - 1.417M \qquad (4)$$

where E_R = rate of sand drift in pounds per rod per hour

A = percent surface clods greater than 0.84 mm. in diameter

R = residue on surface in pounds per acre

K = surface roughness in inches

M = percent moisture in surface soil.

R^2 for this relationship was 0.2457.

The relationship derived with complete logarithmic transformation of all data was

$$E_R = \frac{524}{A^{1.08}R^{0.16}K^{0.85}M^{0.13}} \qquad (5)$$

With the computer adding variables stepwise by contribution to sum of squares, the results were:

Variable	Contribution to R^2
A - clods	0.1122
R - residue	0.1449
K - roughness	0.0453
M - moisture	0.0084
Total R^2 =	0.3108

The curvilinear relationship is better than the linear; however, it only accounts for about 31 percent of the variability and therefore is too poor to be of much value in estimating rates of sand drift from surface variables. It is not clear as to why the relationship between sand drift and the surface variables is so much poorer than the relationship between total soil loss and surface variables obtained on the farmers' fields. One possible reason could be that previous natural erosion had blown off or deposited sand on the plots so that rates of erosion obtained were not in true relationship to the independent variables. Another could be that there was not enough variation in cloddiness or residue to permit evaluation of their influence. Further study is definitely needed in this area.

Abrasive injuries to plants.--Results from the tests to evaluate effect of blowing sand on corn and tomatoes are summarized in table 5. Sugar beets were not large enough at time of tests to sustain damage and no yield or damage data were taken. The data of table 5 indicates some lessened height of corn about 2 months after exposure because of wind

Table 5.--Summary of results of portable wind tunnel tests at Sand Farm, Bowling Green, Ohio, to evaluate abrasive damage to corn and tomatoes.

Crop, land preparation, and time of exposure	Abrasive flux	Plant height on July 7	Yield	Survival
	Tons/rod/hr.	Cm.	Bu./A.	Percent
	---- Wind perpendicular to row ----			
Corn - plowed, harrowed, and planted				
3-minute exposure	0.023	96	-----	---
6-minute exposure	0.019	102	-----	---
9-minute exposure	0.031	86	-----	---
Check	0	124	-----	---
Corn - no tillage				
3-minute exposure	0.009	89	-----	---
Check	0	152	-----	---
Tomatoes - plowed, harrowed, and planted				
3-minute exposure	0.009	---	-----	72
6-minute exposure	0.006	---	-----	53
9-minute exposure	0.006	---	-----	36
Check	0	---	-----	49
	------- Wind parallel to row -------			
Corn - plowed, harrowed, and planted				
3-minute exposure	0.020	130	129.7	---
Check	0	124	121.0	---
Corn - no tillage				
3-minute exposure	0.027	145	131.5	---
Check	0	152	134.1	---
Tomatoes - plowed, harrowed, and planted				
6-minute exposure	0.020	---	-----	67
Check	0	---	-----	49

and blowing sand but there is no definite indication of reduced yield. Plant heights were slightly less on the no-tillage perpendicular plots. However, on parallel plots, no-tillage corn showed slightly higher growth both on the wind tunnel plots and the nonblown check plots. Tomatoes indicate a reduced percent survival with increased time of exposure to wind and sand but the check has a lower survival than the exposed plants, thus casting some doubt on the validity of the results.

The general inconclusiveness of these data because of problems of small and wilted plants at time of testing and the very low abrasive fluxes used clearly indicates a need for further study. Additional tests should be run for longer periods of time, probably three times longer than the 3-, 6-, and 9-minute tests in this study. They should only be run on plots which have not been subjected to natural erosion, where plants are of sufficient size to sustain damage, and when the soil is dry enough so that it can be completely pulverized to assure a constant source of abrasive material for the duration of the test period.

Summary

Field and laboratory investigations designed to gain specific information on the various factors influencing erodibility of cultivated lands in northwestern Ohio were carried out in 1967. The study included: (a) Analysis of climatic data, (b) erodibility tests using a portable wind tunnel, (c) analysis of soil and residue factors related to erodibility, and (d) assessment of effects of abrasive damage on plant growth and crop yield.

The highest wind velocities occur during the period November through April when many fields are bare, freezing and thawing has pulverized the soil, and rainfall from November through February is low, thus making this the most critical period for wind erosion in northwestern Ohio.

Monthly climatic factors are low in comparison to the Great Plains with a maximum of only 10 to 12 percent during the period November through April. The wind erosion hazard therefore is relatively low for the area and what does occur is due to extremely sandy soils, knolls, and because of the intensified tillage and cropping practices used.

Toledo, Ohio, the closest weather station to the study area, has a magnitude of wind erosion forces or capacity of wind to cause soil blowing that is two to three times greater than for other locations in Ohio. The period November through April is the highest. Direction data and ratios of parallel to perpendicular winds indicate that barriers would be most effective if oriented in a NW-SE direction.

Northwestern Ohio soils are potentially more erosive than Great Plains soils. I' values for soils with given percentages of soil fractions greater than 0.84 mm. in diameter were higher than for Great Plains soils. Use of table 2 in this report, which gives I' values in relation to fractions greater than 0.84 mm. in diameter, is recommended when applying the wind erosion equation to northwestern Ohio conditions.

Portable wind tunnel tests indicated that plowing and disking is not a good way to prepare land for corn planting in northwestern Ohio if wind erosion control is desired. Planting in untilled cornstalks, power disking, or "sidewinder" tillage provides much better wind erosion control. Spinks and Ottokee loamy fine sands are far more susceptible to wind erosion than Oakville fine sands, Tedrow loamy sands, Colwood silt loams, or Granby loamy fine sands. It is better to plant rows perpendicular to prevailing wind erosion direction (W-SW) if at all possible. Tunnel losses were nearly three times greater with parallel-to-row winds than with perpendicular-to-row winds.

A number of multiple regression equations expressing wind tunnel soil loss as a function of the independent variables: roughness, cloddiness, surface soil moisture, and amount of residue were developed. Relationships between soil loss and soil moisture were not good; however, several curvilinear relationships were developed which accounted for 79 to 85 percent of the variability in data. A somewhat simplified equation, $E = 16{,}150/A^{2.21}(RK)^{0.74}$ where A is soil cloddiness, R is amount of residue, and K is surface roughness, accounted for about 85 percent of the variability and is recommended for use if estimates of wind tunnel erodibility were to be made on northwestern Ohio soils.

Good data for making comparisons between soil losses measured by the wind tunnel and those calculated with the wind erosion equation are lacking; however, comparisons based on limited natural wind erosion data obtained by Schmidt indicated close agreement between the two methods in 2 out of 14 cases and reasonable agreement on half the sites. The wind erosion equation seriously underestimated erodibility on only 2 out of the 14 sites. More data and study are needed; however, it is believed that the wind erosion equation can be used with judgment in designing wind erosion control practices in northwestern Ohio.

Results of tests to evaluate effects of windblown sand on corn, sugar beets, and tomatoes were inconclusive because of wet soils, low rates of abrasive flux, and small and wilted plants. Limited data showed some lessened height of corn about 2 months after exposure because of wind and blowing sand but there is no definite indication of reduced yield. Tomatoes indicated a reduced percent survival with increased time of exposure to wind and sand but the check with no wind had a lower survival than the exposed plants, thus casting some doubt on the validity of the results. More study is needed after considerable redesign of test procedures.

Recommendations

1.--Farmers in northwestern Ohio should be encouraged to use the no-tillage-plant, the sidewinder-plant, or the power-disk-plant methods of planting corn rather than the plow-plant method if they wish to control wind erosion.

2.--Wind erosion control practices in northwestern Ohio should be designed for the period November through April because erosion hazard is highest during this period.

3.--If at all possible, stripcrops, windbreaks, and crop rows should be oriented in a WNW-SSE direction to be perpendicular to the prevailing WSW wind erosion direction.

4.--Intensive wind erosion control practices should be applied to the Spinks and Ottokee loamy fine sands, especially to knolls and hilltops, because they are far more susceptible to wind erosion than the other soils in northwestern Ohio.

5.--The wind erosion equation can be used with judgment and common sense to design wind erosion control practices in northwestern Ohio. Monthly C' factors and the I' values determined in this study should be used.

6.--More research effort should be expended to obtain better measurements of natural wind erosion that occurs with different farming practices on different soils in northwestern Ohio. Soil catchers should be placed in large fields and numbers of days with blowing sand should be tabulated.

7.--Additional portable wind tunnel tests should be conducted in Ohio on farmers' fields to verify results of this study. The tests should be run on most of the soils included in this study and on any additional soils where wind erosion is a problem.

8.--There is some question about the desirability of attempting to run additional tunnel tests to evaluate abrasive injury to crops because of the difficulties of obtaining plants of the right size at the right time, providing protection from natural erosion, and obtaining a sufficiently serious erosive condition to provide a constant supply of abrasive material. If these obstacles can be overcome, then it is recommended that additional tests involving fewer plots and longer periods of exposure to blowing sand be run.

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Appendix

Westhoven Farm (Secs. 21 and 22, Washington T.), Henry County, Ohio.

Soil Unit: HN-53 Capability Unit: IIIs855 Soil Type: Ottokee loamy fine sand

May 22, 1967. Field plowed and planted to corn with surface planter. One to 2 inches of dry, loose, white to yellow erodible sand on surface. A few fragile clods on surface. No residue. Test site did not stabilize in 9 minutes--average estimated time to stabilize from projection of rate data was 59 minutes. Field topography was undulating with knolls with exceedingly high erosion potential at time of test.

Surface Conditions:

Residue R	0	lbs./acre
Ridge roughness K'	perpendicular 1.6, parallel 1.2	inches
Soil fractions greater than 0.84 mm.	8.5	percent
Moisture content of surface soil	0.8	percent
Soil eroded in tunnel parallel to row	181.1	tons/acre
Soil eroded in tunnel perpendicular to row	55.9	tons/acre

Westhoven Farm (Secs. 21 and 22, Washington T.), Henry County, Ohio.

Soil Unit: Capability Unit: IIIw938 Soil Type: Granby loamy fine sand

May 22, 1967. Field plowed and planted to corn with surface planter. About 1 inch of dry, moderately loose, dark-colored sand on surface. Some clods of medium stability. No residue on surface. Test site stabilized in 4 minutes. Field slightly undulating in topography with no pronounced knolls. Erosion potential of field at time of test was moderate.

Surface Conditions:

Residue R	0	lbs./acre
Ridge roughness K'	perpendicular 2.0, parallel 1.1	inches
Soil fraction greater than 0.84 mm.	31.5	percent
Moisture content of surface soil	2.5	percent
Soil eroded in tunnel parallel to row	3.2	tons/acre
Soil eroded in tunnel perpendicular to row	0.7	ton/acre

Westhoven Farm (Secs. 21 and 22, Washington T.), Henry County, Ohio.

Soil Unit: HN-52 Capability Unit: IVs935 Soil Type: Oakville fine sand

May 22, 1967. Untilled cornland. Soil surface firm and slightly crusted. Few surface clods but good roughness from cultivation of last corn crop. Cornstalks and some weed growth provide excellent residue cover. Test site stabilized in 4 minutes. Field at slightly higher elevation than other parts of farm with uniform slope north to south. This field is rated slightly susceptible to wind erosion.

Surface Conditions:

Residue R	5,363	lbs./acre
Ridge roughness K'	4.0	inches
Soil fractions greater than 0.84 mm.	11.2	percent
Moisture content of surface soil	4.8	percent
Soil eroded in tunnel perpendicular to row	0.3	ton/acre

Westhoven Farm (Secs. 21 and 22, Washington T.), Henry County, Ohio.

Soil Unit: HN-52 Capability Unit: IVs935 Soil Type: Oakville fine sand

May 23, 1967. Cornland tilled with power disk. Surface soil loose but dry to only 1/2- to 1-inch depth. Moderately rough due to mounds and depressions caused by disk. Some cornstalk residue mixed on surface provides only moderately effective vegetative cover. Test site stabilized in 4 minutes. Field at slightly higher elevation than other parts of farm with uniform slope north to south. This field is rated moderately susceptible to wind erosion.

Surface Conditions:

Residue R	1,371	lbs./acre
Ridge roughness K'	2.2	inches
Soil fractions greater than 0.84 mm.	4.4	percent
Moisture content of surface soil	1.9	percent
Soil eroded in tunnel perpendicular to row	3.4	tons/acre

Jones Farm (NW 1/4 sec. 33, Chesterfield T.), Fulton County, Ohio.

Soil Unit: Capability Unit: IIw608 Soil Type: Colwood silt loam

May 23, 1967. Untilled cornland. Planted with surface planter. Soil surface dark-colored, firm, slightly crusted, and moderately dry. Moderately rough from cultivation of previous corn crop. Good residue cover of flattened cornstalks. Field in lee of hill to south and at a considerably lower elevation than surrounding terrain. Tunnel erosion essentially zero. Field rated as not susceptible to wind erosion.

Surface Conditions:

Residue R	3,200	lbs./acre
Ridge roughness K'	2.7	inches
Soil fractions greater than 0.84 mm.	82.3	percent
Moisture content of surface soil	11.7	percent
Soil eroded in tunnel perpendicular to row	0	tons/acre

Jones Farm (NW 1/4 sec. 33, Chesterfield T.), Fulton County, Ohio.

Soil Unit: Capability Unit: IIIs855 Soil Type: Spinks loamy fine sand

May 23, 1967. Untilled cornland. Planted with surface planter. Soil surface light-colored, loose and dry to 1/2- to 1-inch depth. Moderately rough from cultivation of previous corn crop. Fair residue cover of flattened cornstalks. Test site on slope and near top of steep knoll. Test site stabilized in 4 minutes. Tunnel erosion rates low due to moisture near surface and residue cover but field rated as highly susceptible to wind erosion.

Surface Conditions:

Residue R	3,457	lbs./acre
Ridge roughness K'	2.1	inches
Soil fractions greater than 0.84 mm.	7.5	percent
Moisture content of surface soil	1.1	percent
Soil eroded in tunnel perpendicular to row	0.1	ton/acre
Corn yield tunnel site 59.3, check--no tunnel wind	54.7	bu./acre

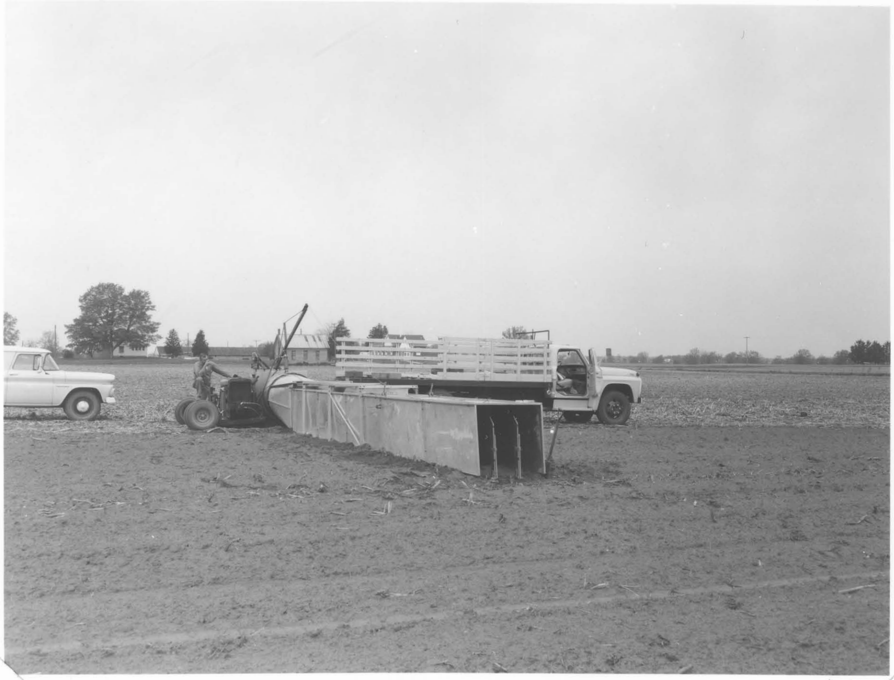
Jones Farm (NW 1/4 sec. 33, Chesterfield T.), Fulton County, Ohio.

Soil Unit: Capability Unit: IIIs855 Soil Type: Spinks loamy fine sand

May 23, 1967. Cornland plowed and planted with surface planter. One to 2 inches of light-colored, loose sand on surface. Field drifted by natural winds and is essentially smooth. Poor and ineffective residue cover. Test site did not stabilize in 9 minutes--estimated time to stabilize from projection of rate data was 26 minutes. Field is located at top of knoll and is rated as highly susceptible to wind erosion.

Surface Conditions:

Residue R	0	lbs./acre
Ridge roughness K'	1.3	inches
Soil fractions greater than 0.84 mm.	4.9	percent
Moisture content of surface soil	0.6	percent
Soil eroded in tunnel perpendicular to row	106.9	tons/acre
Corn yield tunnel site 47.3, check--no tunnel wind	51.8	bu./acre



Jones Farm (NW 1/4 sec. 33, Chesterfield T.), Fulton County, Ohio.

Soil Unit: Capability Unit: IIw608 Soil Type: Colwood silt loam

May 23, 1967. Cornland plowed and planted with surface planter. Soil surface loose, dark-colored, with a relatively thin, dry top layer. Some fragile clods. Poor and ineffective residue cover. Test site stabilized in 4 minutes. Field located at lower elevation on lee side of fairly steep knoll. Wind tunnel erodibility low because of moisture near surface of soil. Field rated as moderately susceptible to wind erosion.

Surface Conditions:

Residue R	0	lbs./acre
Ridge roughness K'	1.5	inches
Soil fractions greater than 0.84 mm.	52.6	percent
Moisture content of surface soil	8.4	percent
Soil eroded in tunnel perpendicular to row	0.2	ton/acre

Jones Farm (NW 1/4 sec. 33, Chesterfield T.), Fulton County, Ohio.

Soil Unit: Capability Unit: IIw608 Soil Type: Colwood silt loam

May 23, 1967. Cornland tilled with "sidewinder" and surface planted. Soil surface loose and fluffy, dark-colored with few stable clods. Fair residue cover of flattened cornstalks. Test site stabilized in 4 minutes. Wind tunnel erodibility low because of moisture near surface and residue cover. Field located at low elevation on lee side of fairly steep knoll. Field rated as moderately susceptible to wind erosion.

Surface Conditions:

Residue R	2,419	lbs./acre
Ridge roughness K'	2.1	inches
Soil fractions greater than 0.84 mm.	64.6	percent
Moisture content of surface soil	8.6	percent
Soil eroded in tunnel perpendicular to row	0	tons/acre

Jones Farm (NW 1/4 sec. 33, Chesterfield T.), Fulton County, Ohio.

Soil Unit: Capability Unit: IIIs855 Soil Type: Spinks loamy fine sand

May 23, 1967. Cornland tilled with "sidewinder" and surface planted. Soil surface loose and light-colored with some fragile clods. Fair residue cover of cornstalks. Wind tunnel erodibility low because of moisture near surface and residue cover. Field located on slope of knoll at higher elevation than other parts of farm. Field rated as moderate to highly susceptible to wind erosion.

Surface Conditions:

Residue R	2,088	lbs./acre
Ridge roughness K'	2.2	inches
Soil fractions greater than 0.84 mm.	5.2	percent
Moisture content of surface soil	0.6	percent
Soil eroded in tunnel perpendicular to row	0.6	ton/acre
Corn yield tunnel site 61.7, check--no tunnel wind	71.5	bu./acre

Chambers Farm (Secs. 19 and 20, Liberty T.), Wood County, Ohio.

Soil Unit: WD-S7 Capability Unit: IIw922 Soil Type: Tedrow loamy sand

May 25, 1967. Plowed land for corn. Not planted. Soil surface cloddy, dark-colored, moderately rough, with only 1/2-inch layer of dry topsoil. Poor residue cover. Field level, large, and exposed to natural winds. Field essentially nonerodible at time of test and rated as only slightly susceptible to wind erosion.

Surface Conditions:

Residue R	0	lbs./acre
Ridge roughness K'	1.6	inches
Soil fractions greater than 0.84 mm.	42.7	percent
Moisture content of surface soil	5.6	percent
Soil eroded in tunnel perpendicular to row	0.2	ton/acre

Chambers Farm (Secs. 19 and 20, Liberty T.), Wood County, Ohio.

Soil Unit: WD-S7 Capability Unit: IIw922 Soil Type: Tedrow loamy sand

May 25, 1967. Plowed land for corn. Not planted. Surface raked to simulate disking or harrowing of ground prior to corn planting. Soil surface loose, fairly cloddy, relatively smooth, with only shallow layer of dry topsoil. Field level, large, and exposed to natural winds. Wind tunnel erodibility low due to soil moisture near surface. Field rated as moderately erodible when in condition tested.

Surface Conditions:

Residue R	0	lbs./acre
Ridge roughness K'	1.2	inches
Soil fractions greater than 0.84 mm.	51.5	percent
Moisture content of surface soil	8.2	percent
Soil eroded in tunnel perpendicular to row	0.3	ton/acre

Appendix Table 1.--Conditions of soil structure, surface roughness, crop residue, soil moisture, and wind tunnel erodibility of 42 farmer field sites tested with portable tunnel in northwestern Ohio, May 22-26, 1967.

Site no.	Location and treatment or crop	Soil type	Soil fraction > 0.84 mm.	Ridge roughness		Crop residue		Surface soil moisture	Tunnel wind direction	Tunnel soil loss
				Tunnel	Measured K_r	Cover	Amount			
			Percent	Inches	Inches	Percent	Lbs./A.	Percent		Tons/A.
1	Westhoven farm, Henry County,	Ottokee loamy	11.6	1.2	3.0	0	0	0.85	Parallel row	144.8
2	plowed, disked, and planted to	fine sand	14.1	1.3	3.1	0	0	0.23	Parallel row	11.8
3	corn		6.2	1.0	2.4	0	0	1.27	Parallel row	386.5
4			6.2	1.6	1.4	0	0	0.20	Perpendicular row	42.6
5			6.2	1.3	2.1	0	0	1.35	Perpendicular row	26.3
6			7.0	1.9	1.9	0	0	0.79	Perpendicular row	98.5
7	Westhoven farm, Henry County,	Granby loamy	16.4	1.1	3.1	0	0	7.07	Parallel row	3.1
8	plowed, disked, and planted to	fine sand	24.2	1.2	1.9	0	0	2.17	Parallel row	5.1
9	corn		34.4	1.0	1.1	0	0	0.91	Parallel row	1.6
10			40.6	1.7	2.6	0	0	1.45	Perpendicular row	1.4
11			40.6	1.8	2.4	0	0	0.81	Perpendicular row	0.3
12			32.8	2.4	2.2	0	0	2.66	Perpendicular row	0.35
13	Westhoven farm, Henry County,	Oakville fine	12.5	3.9	0.6	-	4,960	5.30	Perpendicular row	0.02
14	untilled cornstalks	sand	9.4	3.5	0.9	-	5,340	3.60	Perpendicular row	0.01
15			11.7	4.5	0.7	-	5,790	5.60	Perpendicular row	0.80
16	Westhoven farm, Henry County,	Oakville fine	3.9	2.0	0	-	1,902	2.10	Perpendicular row	3.30
17	power-disked cornstalks	sand	4.7	2.1	0	-	1,300	1.80	Perpendicular row	4.00
18			4.7	2.6	0	-	910	1.90	Perpendicular row	2.90
19	Jones farm, Fulton County,	Colwood silt	81.2	2.6	0.5	83	2,390	7.60	Perpendicular row	0.001
20	no tillage, plant in cornstalks	loam	81.2	2.7	0.6	78	3,820	11.40	Perpendicular row	0.001
21			84.4	2.8	0.4	66	3,390	16.00	Perpendicular row	0.004
22	Jones farm, Fulton County,	Spinks loamy	7.8	1.7	1.3	41	4,030	0.20	Perpendicular row	0.029
23	no tillage, plant in cornstalks	fine sand	6.2	2.4	1.2	23	2,880	1.50	Perpendicular row	0.014
24			8.6	2.3	0.7	61	3,460	1.60	Perpendicular row	0.070
25	Jones farm, Fulton County,	Spinks loamy	6.2	1.0	0.9	0	0	0.80	Perpendicular row	110.1
26	plowed and planted	fine sand	3.1	1.3	0.6	0	0	0.80	Perpendicular row	103.0
27			5.5	1.5	1.0	0	0	0.30	Perpendicular row	107.0
28	Jones farm, Fulton County,	Colwood silt	56.2	1.6	2.0	0	0	6.90	Perpendicular row	0.05
29	plowed and planted	loam	51.6	1.5	2.1	0	0	8.40	Perpendicular row	0.16
30			50.0	1.4	1.6	0	0	9.90	Perpendicular row	0.31
31	Jones farm, Fulton County,	Colwood silt	59.4	2.1	1.0	36	1,971	5.60	Perpendicular row	0.014
32	sidewinder and plant	loam	67.2	2.3	1.0	39	3,573	9.20	Perpendicular row	0.008
33			67.2	1.8	0.8	38	1,712	11.00	Perpendicular row	0.022
34	Jones farm, Fulton County,	Spinks loamy	4.7	2.3	1.1	34	2,380	0.70	Perpendicular row	1.10
35	sidewinder and plant	fine sand	5.5	2.0	2.1	27	1,764	0.30	Perpendicular row	0.43
36			5.5	2.4	1.1	19	2,120	0.80	Perpendicular row	0.31
37	Chambers farm, Wood County,	Tedrow loamy	40.6	1.1	0.9	0	0	6.15	Perpendicular row	0.174
38	rough plowed	sand	40.6	1.8	0.9	0	0	4.98	Perpendicular row	0.055
39			46.9	1.8	1.6	0	0	5.52	Perpendicular row	0.310
40	Chambers farm, Wood County,	Tedrow loamy	48.4	1.3	0.2	0	0	8.46	Perpendicular row	0.530
41	plowed and raked	sand	48.4	1.0	0.1	0	0	7.50	Perpendicular row	0.30
42			57.8	1.2	0.2	0	0	8.55	Perpendicular row	0.18

Sand Farm (NE 1/4 SW 1/2 SW 1/4 sec. 16, Plain T.), Wood County, Ohio.

Soil Unit: Capability Unit: IIIs855 Soil Type: Ottokee loamy fine sand

May 24, 1967. Plowed, harrowed, and planted sugar-beet plots. Beet plants have emerged but are very small. Plots were hand-raked to break crust and increase erodibility. Some fairly stable clods. After raking, soil surface contained about 1 inch of dry, loose, light-colored sand. No residue. Field is on knoll in undulating terrain. Plots rated moderately susceptible to wind erosion.

Surface Conditions:

Residue R		0	lbs./acre
Ridge roughness K'	perpendicular	1.2	inches
Soil fractions greater than 0.84 mm.		8.6	percent
Moisture content of surface soil		1.6	percent
Rate of sand drifting, 3-minute-duration	perpendicular	.010	ton/rd./hr.
Plant survival		---	percent
Rate of sand drifting, 6-minute-duration	perpendicular	.011	ton/rd./hr.
Plant survival		---	percent
Rate of sand drifting, 9-minute-duration	perpendicular	.016	ton/rd./hr.
Plant survival		---	percent

Sand Farm (NE 1/4 SW 1/2 SW 1/4 sec. 16, Plain T.), Wood County, Ohio.

Soil Unit: Capability Unit: IIIs855 Soil Type: Ottokee loamy fine sand

May 24, 1967. Untilled sugar-beet plots. Beet plants have emerged but are very small. One to 2 inches of dry, loose, light-colored sand on surface. Considerable sand drifting by natural wind has occurred. Fairly good cover composed of soybean residue and weeds. Field is on knoll in undulating terrain. Plot has moderate to high wind erosion susceptibility.

Surface Conditions:

Residue R		743	lbs./acre
Ridge roughness K'	perpendicular	1.8	inches
Soil fractions greater than 0.84 mm.		8.8	percent
Moisture content of surface soil		1.5	percent
Rate of sand drifting, 3-minute-duration	perpendicular	.002	ton/rd./hr.
Plant survival		---	percent

Sand Farm (NE 1/4 SW 1/2 SW 1/4 sec. 16, Plain T.), Wood County, Ohio.

Soil Unit: Capability Unit: IIIs855 Soil Type: Ottokee loamy fine sand

May 24, 1967. Plowed, harrowed, and planted corn plots. Corn plants 1 to 2 inches high. One to 2 inches of loose, light-colored sand on surface. Some drifting of sand by natural wind. Essentially no residue. Field on knoll in undulating terrain. Plots highly susceptible to wind erosion.

Surface condition	Wind direction and duration of exposure						No wind (Ck.)
	Parallel to row			Perpendicular to row			
	3 min.	6 min.	9 min.	3 min.	6 min.	9 min.	
Sand drift, ton/rd./hr.	.02	*	*	.023	.019	.031	*
Plant height 7-6-67, cm.	130	*	*	96	102	86	124
Yield, bu./acre	129.7	*	*	*	*	*	121
Soil water, %	3.19	*	*	1.04	2.24	0.83	*
Clods > 0.84 mm. dia., %	8.1	*	*	7.8	6.2	7.8	*
Roughness, inches	1.3	*	*	2.0	1.7	1.9	*
Residue, lbs./acre	0	*	*	0	0	0	*

* No test or not applicable.

Sand Farm (NE 1/4 SW 1/2 SW 1/4 sec. 16, Plain T.), Wood County, Ohio.

Soil Unit: Capability Unit: IIIs855 Soil Type: Ottokee loamy fine sand

May 24, 1967. Corn planted on untilled land. Corn plant 1 to 2 inches high. One to 1 1/2 inches of loose, light-colored sand on surface. Some drifting of sand by natural wind. Good cover of soybean and weed residue. Field on knoll in undulating terrain. Plots moderately susceptible to wind erosion.

Surface condition	Wind direction and duration of exposure						No wind (Ck.)
	Parallel to row			Perpendicular to row			
	3 min.	6 min.	9 min.	3 min.	6 min.	9 min.	
Sand drift, ton/rd./hr.	.027	*	*	.009	*	*	*
Plant height 7-6-67, cm.	145	*	*	89	*	*	152
Yield, bu./acre	131.5	*	*	*	*	*	134.1
Soil water, %	4.7	*	*	1.6	*	*	*
Clods > 0.84 mm. dia., %	5.7	*	*	7.8	*	*	*
Roughness, inches	1.4	*	*	1.5	*	*	*
Residue, lbs./acre	973	*	*	740	*	*	*

* No test or not applicable.

Sand Farm (NE 1/4 SW 1/2 SW 1/4 sec. 16, Plain T.), Wood County, Ohio.

Soil Unit: Capability Unit: IIIs855 Soil Type: Ottokee loamy fine sand

May 24, 1967. Plowed, harrowed, and planted tomato plots. Tomato plants were approximately 6 inches high. They were set in the morning of the day of testing and exposed to blowing sand in the tunnel about 4 hours after planting. The plants were in a wilted condition at time of tunnel tests. Soil was hand-raked prior to test and had a 1- to 2-inch layer of loose, light-colored, dry sand on the surface. No residue. Field on knoll in undulating terrain. Plots highly susceptible to wind erosion.

Surface condition	Wind direction and duration of exposure						No wind
	Parallel to row			Perpendicular to row			
	3 min.	6 min.	9 min.	3 min.	6 min.	9 min.	(Ck.)
Sand drift, ton/rd./hr.	*	.020	*	.009	.006	.006	*
Plant survival 6-7-67, %	*	67	*	72	53	36	49
Yield, bu./acre	*	*	*	*	*	*	*
Soil water, %	*	1.13	*	.96	1.04	1.43	1.13
Clods > 0.84 mm. dia., %	*	6.4	*	14.6	10.4	11.3	8.3
Roughness, inches	*	1.2	*	1.3	1.6	1.4	*
Residue, lbs./acre	0	0	0	0	0	0	0

* No test or not applicable.

Appendix Table 2.--Conditions of soil structure, surface roughness, crop residue, soil moisture, rate of blowing sand, crop height, crop survival, and yield of 42 sites tested with portable tunnel on Ottokee loamy fine sand on Ohio Agricultural Experiment Station Sand Farm, May 22-26, 1967.

Site no.	Plot no.	Crop and treatment	Tunnel wind direction	Soil fraction > 0.84 mm.	Ridge roughness		Crop residue		Surface soil moisture	Exposure time	Rate of sand flow	Crop height 6 weeks after exposure	Crop survival 2 weeks after exposure	Crop yield
					Tunnel	Measured K_r	Cover	Amount						
				Percent	Inches	Inches	Percent	Lbs./A.	Percent	Min.	Tons/rd./hr.	Cm.	Percent	Bu./A.
1	12	Sugar beets, plowed	Perpendicular row	4.7	1.2	1.0	0	0	1.43	6	0.007	---	--	----
2	11	Sugar beets, plowed	Perpendicular row	7.8	1.3	0	0	0	2.17	9	0.019	---	--	----
3	10	Sugar beets, no tillage	Perpendicular row	8.8	1.7	1.7	-	830	1.32	3	0.001	---	--	----
4	9	Sugar beets, plowed	Perpendicular row	12.3	1.4	1.1	0	0	1.38	3	0.011	---	--	----
5	8	Sugar beets, no tillage	Perpendicular row	8.8	1.9	1.7	-	620	1.12	3	0.004	---	--	----
6	7	Sugar beets, plowed	Perpendicular row	12.3	1.2	1.1	0	0	1.99	3	0.009	---	--	----
7	6	Sugar beets, plowed	Perpendicular row	4.7	1.0	1.0	0	0	1.81	6	0.011	---	--	----
8	5	Sugar beets, plowed	Perpendicular row	7.8	1.1	0	0	0	1.68	9	0.016	---	--	----
9	4	Sugar beets, plowed	Perpendicular row	10.7	1.1	0	0	0	1.02	9	0.014	---	--	----
10	3	Sugar beets, plowed	Perpendicular row	12.3	1.3	1.1	0	0	2.05	3	0.011	---	--	----
11	2	Sugar beets, plowed	Perpendicular row	4.7	1.2	1.0	0	0	1.24	6	0.016	---	--	----
12	1	Sugar beets, no tillage	Perpendicular row	8.8	1.8	1.7	-	780	2.17	3	0.002	---	--	----
13	8	Corn, 2" high, no tillage	Perpendicular row	7.8	1.3	1.7	13.3	850	3.44	3	0.008	112	--	----
14	1	Corn, 2" high, no tillage	Perpendicular row	7.8	1.8	1.7	9.5	480	0.72	3	0.010	107	--	----
15	2	Corn, 2" high, plowed	Perpendicular row	7.8	1.5	1.1	0	0	1.67	3	0.032	97	--	----
16	3	Corn, 2" high, plowed	Perpendicular row	6.2	1.6	1.0	0	0	2.33	6	0.020	94	--	----
17	4	Corn, 2" high, plowed	Perpendicular row	7.8	2.2	0	0	0	1.02	9	0.020	86	--	----
18	5	Corn, 2" high, plowed	Perpendicular row	6.2	1.5	1.0	0	0	1.58	6	0.031	76	--	----
19	6	Corn, 2" high, plowed	Perpendicular row	7.8	1.2	0.2	0	0	0.76	3	0.034	74	--	----
20	7	Corn, 2" high, plowed	Perpendicular row	7.8	1.8	0	0	0	0.82	9	0.034	71	--	----
21	9	Corn, 2" high, no tillage	Perpendicular row	7.8	1.4	1.7	12.7	990	0.65	3	0.009	46	--	----
22	10	Corn, 2" high, plowed	Perpendicular row	7.8	1.8	0	0	0	0.67	9	0.040	104	--	----
23	11	Corn, 2" high, plowed	Perpendicular row	7.8	3.4	2.0	0	0	0.68	3	0.002	117	--	----
24	12	Corn, 2" high, plowed	Perpendicular row	6.2	2.0	1.0	0	0	2.82	6	0.006	132	--	----
25	18	Corn, 2" high, no tillage	Parallel row	4.7	1.6	1.7	14.6	1,100	4.20	3	0.021	160	--	145.3
26	17	Corn, 2" high, plowed	Parallel row	6.2	1.3	1.1	0	0	3.01	3	0.023	135	--	128.8
27	16	Corn, 2" high, plowed	Parallel row	7.8	1.3	1.1	0	0	2.87	3	0.046	122	--	123.4
28	15	Corn, 2" high, no tillage	Parallel row	6.2	1.2	1.7	17.7	1,330	4.21	3	0.010	147	--	108.1
29	14	Corn, 2" high, no tillage	Parallel row	6.2	1.4	1.7	11.0	490	5.56	3	0.015	124	--	141.1
30	13	Corn, 2" high, plowed	Parallel row	10.3	1.5	1.1	0	0	3.69	3	0.026	130	--	136.9
31	12	Tomatoes, 4" high, plowed	Perpendicular row	20.3	1.4	0.7	0	0	0.60	3	0.004	---	69	----
32	11	Tomatoes, 4" high, plowed	Perpendicular row	10.3	1.3	0	0	0	1.61	9	0.006	---	36	----
33	10	Tomatoes, 4" high, plowed	Perpendicular row	12.5	1.9	0	0	0	0.88	6	0.005	---	25	----
34	9	Tomatoes, 4" high, plowed	Perpendicular row	14.1	1.5	0	0	0	0.97	9	0.004	---	50	----
35	8	Tomatoes, 4" high, plowed	Perpendicular row	10.9	1.0	0.7	0	0	0.82	3	0.010	---	64	----
36	7	Tomatoes, 4" high, plowed	Perpendicular row	9.4	1.3	0	0	0	1.27	6	0.003	---	73	----
37	6	Tomatoes, 4" high, plowed	Perpendicular row	9.4	1.5	0	0	0	1.71	9	0.008	---	21	----
38	5	Tomatoes, 4" high, plowed	Perpendicular row	9.4	1.7	0	0	0	1.07	6	0.011	---	62	----
39	4	Tomatoes, 4" high, plowed	Perpendicular row	12.5	1.6	0.7	0	0	1.46	3	0.013	---	82	----
40	1	Tomatoes, 4" high, plowed	Parallel row	7.8	1.3	0.5	0	0	0.84	6	0.025	---	53	----
41	3	Tomatoes, 4" high, plowed	Parallel row	6.2	1.2	0.7	0	0	1.12	6	0.012	---	80	----
42	5	Tomatoes, 4" high, plowed	Parallel row	6.2	1.0	0.4	0	0	1.42	6	0.022	---	67	----