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Wind Erosion Estimates with RWEQ and WEQ

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INTRODUCTION

Soil erosion by wind can occur whenever the wind speed is above the threshold required to erode soil if the soil surface is not protected with growing crops, crop residues, soil roughness, or wind barriers. When vast areas of flat landscape in arid or semiarid regions are left bare because of fires, droughts, or mismanagement; wind erosion can become a major problem. Wind is an effective agent in the detachment, movement, and deposition of huge quantities of fine soil material, as evidenced by deep loess soils and large sand dunes on every continent. Wind erosion occurs not only on Earth but also on many planets (Greeley and Iverson, 1985). Health problems due to wind blown dust in the Pacific Northwest predate agricultural activities (Lewis and Clark, 1806). Accounts of livestock deaths in the 1930's in the Central Great Plains (Malin, 1946) are evidence that wind may present environmental and health problems to man and animals. To minimize the impact of man's activities, the factors responsible for wind erosion must be understood.

Field and laboratory research was started in the 1930's to identify factors that control or accelerate wind erosion. A simultaneous study of all factors contributing to wind erosion is impossible; therefore, the traditional approach has been to study one factor at a time. While recognizing that many factors are interrelated, assumptions must be made on how these factors independently affect wind erosion. The combination of all these factors is the basis for a wind erosion model. The first wind erosion model, called the Universal Wind Erosion Equation (USDA, 1961), was updated and published as the Wind Erosion Equation (WEQ) (Woodruff and Siddoway, 1965). The WEQ was the only model available to plan wind erosion control systems until the Revised Wind Erosion Equation (RWEQ) was released (Fryrear et al., 1998).

The objective of this report is to compare measured erosion from 15 instrumented sites with erosion estimates using the WEQ and RWEQ models. WEQ and RWEQ utilize the same basic inputs, but the technology that uses these inputs is entirely different. An additional objective is to use both models to compare estimated erosion from typical cropping systems from different regions of the country. Before wind erosion estimates with RWEQ and WEQ can be compared, the terms *transport mass* and *average soil erosion* must be defined. The output of WEQ is the *average soil erosion*, expressed in mass per unit area per annum, that could occur from a given field length (Woodruff and Siddoway, 1965). *Transport mass* is the mass of soil being transported by wind in a band of unit width that extends from the soil surface to a specific height of 2 meters with RWEQ. WEQ does not specify the height (Woodruff and Siddoway, 1965). *Average soil erosion* as used in RWEQ is the quantity of soil material being transported (mass per unit width) divided by the field length to the upwind boundary. An understanding of these two terms is essential to the comparison of RWEQ and WEQ.

Wind Erosion Equation (WEQ)

The WEQ was reported by Woodruff and Siddoway (1965), but the basic technology had been described as a Universal Wind Erosion Equation (USDA, 1961). The background data for WEQ was summarized in the classic work reported by Chepil and Woodruff (1963). Since the first publication of WEQ, modifications were suggested by Woodruff and Armbrust (1968), Skidmore and Woodruff (1968), Skidmore et al., (1970), Bondy et al., (1980), Lyles (1983), and Skidmore and Nelson, (1992). The WEQ was modified to permit the estimate of soil erosion for time periods shorter than one year (Bondy et al., 1980). However, Bondy states, "no experimental data base exists for using WEQ for periods of less than one year." The foundation of WEQ is the soil erodibility factor (*I*). The definition of *I* is the potential soil erosion in tons per hectare per annum from a wide, unsheltered, isolated field with a bare, smooth, non-crusted surface. *I* values were developed from wind tunnel and field measurements of soil erodibility based on climatic conditions in the vicinity of Garden City, Kansas from 1954 to 1956.

To illustrate the output from WEQ an example with the inputs of *I* = 108, C = 80, K = 0.8, and V = 750 was used with the "E" tables from the NRCS National Agronomy Manual. The input values are defined in Table 1. The maximum average annual soil erosion occurs at a field length of 1829 meters or greater (Fig. 1). For field lengths greater than 1829 m (soil erosion is constant), the annual transport mass increases from 12,000 kg m^{-1}-width at 2,000 meters to 18,000 kg m^{-1}-width at 3,000 meters (Fig. 1). Maximum mass transport measured from a single event was 1,430 kg m^{-1}-width (Fryrear and Saleh, 1996). This single event accounted for 42% of the total erosion from February 27, 1990 to May 25, 1993. To have 18,000 kg m^{-1}-width would require thirteen extreme events each year.

Revised Wind Erosion Equation (RWEQ)

The need for new science that permits the input of management factors impacting soil erosion fostered the development of RWEQ (Fryrear et al., 1998; Fryrear et al., 2000). RWEQ is a combination of empirical and process modeling and is the first wind erosion model extensively tested under field conditions within and outside the Great Plains. Wind is the basic driving force in RWEQ, but regardless of the soil type, you cannot erode more soil than the wind has the capacity to transport. The wind factor, soil erodible fraction, soil crust, soil roughness, growing crops, flat and standing residues (Table 1) terms are used to determine the maximum transport capacity and critical field length necessary to compute maximum transport capacity and transport mass for any field length (Fryrear and Saleh,

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Figure 1. WEQ estimated erosion and transport mass as a function of field length.

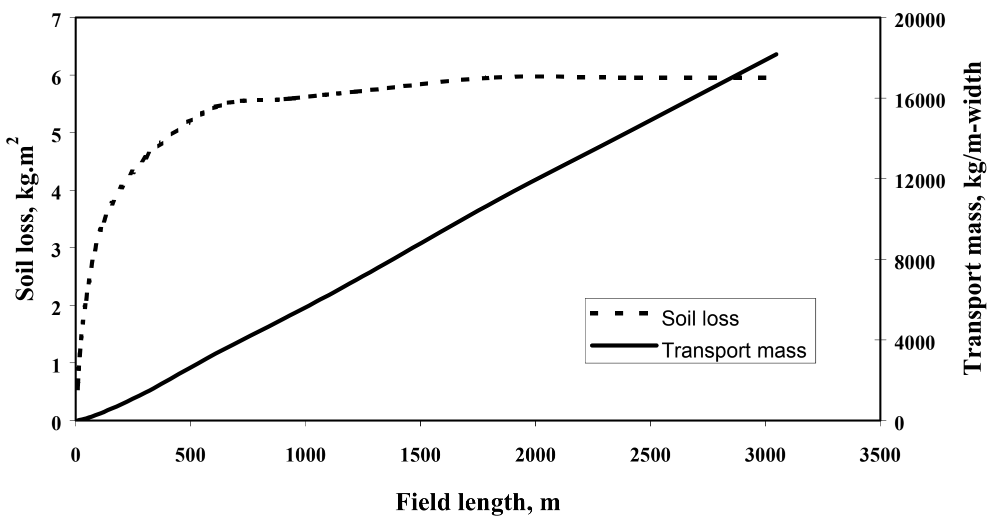
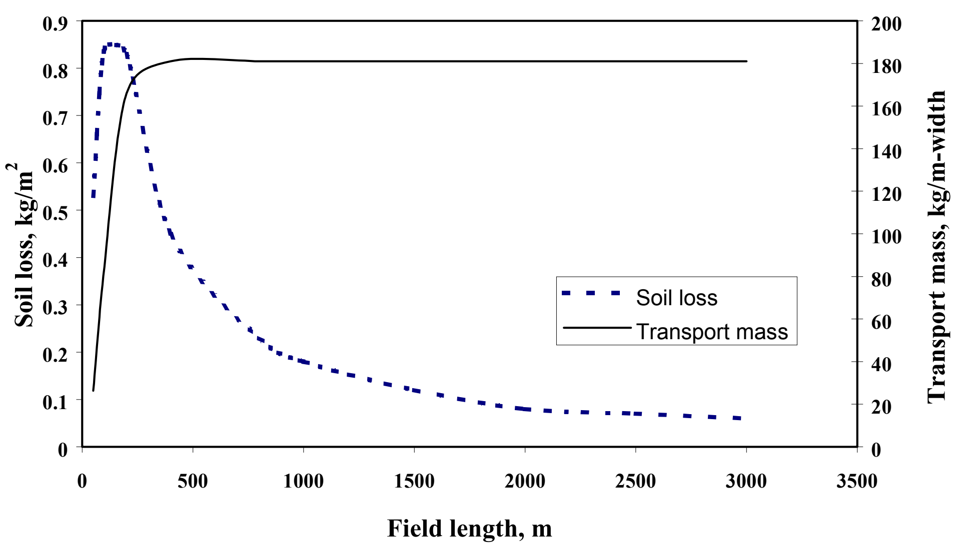


Figure 2. RWEQ estimated average soil loss and estimated tranport mass as a function of field length.



1996). The transport mass at a specific field length divided by field length gives average soil erosion for the upwind field.

To illustrate the basic mechanics of RWEQ, the transport mass for one erosion event is shown in Figure 2. In this event the transport mass is zero at field length zero. As field length increases, transport mass increases rapidly, but begins to level off until the maximum transport capacity has been achieved (Fig. 2). For wind strips or barriers to be effective, they must be spaced less than *s* (89 meters for this event). Over time there will be considerable material removed from the first 89 meters.

Average soil erosion increases until the field length is slightly greater than *s*, then decreases for longer fields but never reaches zero (Fig. 2). The highest soil erosion per unit area occurs from fields that are slightly longer than *s*.

The RWEQ model allows the calculation of maximum soil loss within the field. The maximum soil erosion occurs for field lengths of 0.707*s* (Fig. 2). Average soil erosion represents the soil eroded from the entire upwind field. Comparisons of RWEQ and WEQ soil erosion estimates will be based on average soil erosion with RWEQ, not the maximum soil erosion within the field.

Comparison of RWEQ and WEQ Science

The RWEQ and WEQ models will both estimate soil erosion by wind. The sciences used to describe the erosion process and the influence of climate are two areas of major differences. The cornerstone of RWEQ is the wind, and in WEQ, it is the soil erodibility. With RWEQ if the wind force

Table 1. Input parameters for the Wind Erosion Equation (WEQ) and the Revised Wind Erosion Equation (RWEQ)

WEQ		RWEQ	
I	Soil erodibility index, is potential soil loss in tons per ac per annum from a wide, unsheltered, isolated field with a bare smooth noncrusted surface in vicinity of Garden City, Kansas during 1954-56. May be determined by standard dry sieving procedure and sieving-soil erodibility table. May include Knoll less than 500 feet.	**EF**	Erodible Fraction computed from soil properties or from standard dry sieving procedure.
F_s	Mechanical stability of surface crust is considered of little consequence for annual estimates.	**SCF**	Soil Crust Factor computed from clay and organic matter contents.
K	Ridge roughness coefficient is a roughness other than. Roughness is decayed that caused by clods or vegetation with rainfall. Can be estimated or can be determined from a linear measure of surface roughness.	**K**	Includes both ridge and random measure of roughness other than erodibility I_s for windward slopes. Measured with roughness instruments.
C	Climatic Factor contains annual wind speed and rainfall temperature terms. Modified with erosive wind energy distribution for management period method.	**WF**	Weather Factor wind component computed with 500 wind speed values for each 15 day or less time period. Wind adjusted for number and amount of rainfall events and snow cover. Wind is computed for four directions for each time period.
L	Field Length is total distance across a given field measured along the prevailing wind direction minus the length sheltered by a barrier if present.	**Field**	Input field size and orientation model computes four lengths for each time period. Winds are modified by barrier depending on barrier density, height, and velocity. Adjustments are internal to the program.
V	Quantity of vegetative cover expressed as their small grain equivalent. Considers the quantity (R), Kind (S), and orientation (Ko).	**COG**	Crops On Ground includes flat cover, standing silhouette, and growing crop canopy. Residues are decomposed based on crop, rainfall, and temperature. Standing residues are flattened and buried with tillage operations.
		Hills	Modify wind speeds. Depending on slope and height, hill may increase erosion because of increased velocity. Treating hills as separate field allows adjustments in soil Erodibility fraction and residue cover.

Table 2. Site locations, elevation, annual rainfall, and soil texture data for fifteen locations in the USA where wind erosion was measured.

Site	Longitude	Latitude	Elevation	Sand	Silt	Clay	OM	$CaCO_3$	Rainfall
	----- degrees -----		-- m --	------ Average percentage (%) ------					-- mm --
Mabton, WA	120.05	46.23	216	191	82	13	5	0.44	T
Prosser, WA #1	119.66	46.17	351	191	48	46	6	0.72	T
Prosser, WA #2	119.63	46.16	357	191	44	50	6	0.66	T
Sidney, NE	103.00	41.22	1311	406	36	46	18	1.43	0.0
Elkhart, KS	101.87	37.08	1062	426	68	22	10	0.77	0.0
Eads, CO	102.83	38.50	1284	356	29	39	32	0.92	1.0
Akron, CO	103.15	40.18	1341	417	25	53	22	1.00	2.0
Portales, NM**	103.21	34.16	1268	406	65	27	8	0.70	1.0
Crown Point, IN	87.35	41.22	177	915	75	14	11	1.60	0.7
Martin-C, TX*	101.90	32.15	803	419	43	42	15	0.80	T
Martin-C, TX*	101.93	32.31	843	419	60	22	18	0.30	1.0
Martin-C, TX*	101.79	32.36	838	419	84	10	6	0.20	0.0
Plains E, TX*	102.69	33.19	856	356	76	16	8	0.30	1.0
Plains B, TX*	102.63	33.20	856	356	81	4	15	0.20	1.0
Big Spring, TX	101.49	32.27	762	470	83	9	8	0.17	1.0

* These sites were rectangular fields

** 53 ha circular field. Sites not marked with * were 2.5 ha circles.

Table 3. Measured soil erosion and estimated soil erosion with the wind erosion equation (WEQ) and the Revised Wind Erosion Equation (RWEQ) for fifteen sites in the USA.

Site	Periods	Measured	WEQ	RWEQ
Mabton, WA*	12/12/90-04/28/91	3.68	7.01	3.85
Prosser #1 WA	12/03/91-03/25/92	0.17	0.58	0.25
Prosser #2 WA	06/10/92-06/15/93	0.32	29.13	1.05
Sidney, NE	10/31/90-05/07/91	2.29	0.11	5.65
Elkhart, KS	12/04/91-04/15/92	12.86	25.35	16.09
Eads, CO	10/30/90-05/07/91	2.43	4.30	2.76
Akron, CO	10/27/88-05/26/89	0.83	4.98	6.59
Akron, CO	10/25/89-04/29/90	1.10	3.03	0.38
Portales, NM	11/24/94-04/06/95	0.01	21.52	0.13
Crown Point, IN	01/01/90-12/30/90	31.21	0.00	25.24
Martin County #1, TX	01/24/95-07/05/95	0.30	5.47	0.63
Martin County #2, TX	01/11/95-05/23/95	0.80	5.47	1.01
Martin County #3, TX	01/24/95-07/05/95	0.30	10.82	0.92
Plains, TX EE	12/13/94-05/24/95	2.20	7.69	0.54
Plains, TX YB	12/13/94-05/24/95	1.60	8.09	1.39
Big Spring, TX*	01/10/90-06/04/90	20.96	7.42	18.60

*Sites with erosion events used to calibrate RWEQ.

is great enough even rocks and clods may be moved.

With WEQ, you first determine the soil texture and then multiply by the climatic factor, but if the climatic factor drops below 10 it is almost impossible to estimate any erosion regardless of soil texture. RWEQ estimates transport mass then divides by field length to compute the average soil erosion from the entire field. WEQ estimates the average soil erosion for various field lengths. With WEQ, the transport mass must increase without limits for the average soil erosion (Fig. 1) to remain constant for large fields. This does not agree with Bagnold's theory (1943) that the wind has a limited capacity to transport material. This does not agree with Chepil's (1957) statement "Rate of soil flow increased with distance downwind until, if the field was large enough, it reached a maximum that a wind of a given velocity can carry." For large fields there may be an increase in transport due to the dust carried in suspension but this portion is small compared to the portion being transported in suspension, saltation, and surface creep within 2 meters of the soil surface. The wind may sort the surface material and pick up finer material as it loses larger particles, but the total transport cannot increase without limit. As the field length exceeds the critical field length, and transported mass continues to increase the average soil loss for the entire upwind field decreases (Fig. 2).

Comparison of Measured Erosion with RWEQ and WEQ Estimates

RWEQ and WEQ erosion estimates were tested against measured soil erosion from 15 sites (Table 2 & 3). The measurement periods are from 4 to 23 months. Measured erosion from individual events are summed for the entire measurement period. Estimated erosion with RWEQ is based on the same measurement period and on weather and soil surface conditions at the site. A weather file using Weibull coefficients for wind speed (Skidmore and Tatarko, 1990) was developed from the measured weather data. WEQ weather was from the closest location, but soil erodibility *I* was based on measured soil properties at the site. Soil roughness and surface residue conditions at the beginning of the measurement period are used to initialize RWEQ and as initial input for WEQ. Changes in soil surface roughness or residue levels due to weathering and decomposition are computed in RWEQ using equations within the program (Fryrear et al., 1998). With WEQ the model operator (called the planner) must input if, when, and the magnitude of any adjustments in soil roughness or residue levels. RWEQ erosion estimates from the 15 sites agree with the measured erosion (Fryrear et al., 1998) even when annual rainfall was 915 mm (Crown Point, Indiana) or was less than 191 mm (Prosser, Washington). The significant coefficient of determination ($r^2 = 0.927$) is evidence that with good input data RWEQ gives excellent estimates of soil erosion. The correlation between measured soil erosion and estimated soil erosion with WEQ was not significant ($r^2 = 0.01$)*. The WEQ estimated zero erosion for Crown Point, IN (C = 6) and excessive erosion for Portales, NM (C = 120) exemplify the limitations of WEQ science (Table 3). WEQ does not reflect other management techniques such as standing residues and soil roughness from the 53 ha circular site at Portales.

Estimated Erosion with Typical Management Systems

Typical management systems for different regions of the country and estimates of soil erosion with WEQ were provided by USDA-NRCS personnel. The management system for winter wheat + sorghum + fallow were provided by Bud Davis (Kansas), Dr. P. Sutherland (Colorado), and Gary Tibke (Wyoming and Wisconsin). These management

*WEQ erosion estimates provided by Gary Tibke, NRCS Cooperating Scientist, Manhattan, KS.

systems were input into RWEQ by the author. Soil losses were estimated using the closest available weather site for both WEQ and RWEQ. The correlation of estimated erosion ($kg/m^2/yr$) with WEQ and RWEQ was not significant.

$$WEQ = 1.036 + 1.289\, RWEQ \quad r^2 = 0.21 \qquad [1]$$

With RWEQ the operator does not input residue levels because initial residue quantity and status (flat or standing) is based on crop yields (Schomberg and Steiner, 1997) and tillage operations. Residue decomposition is computed based on crop and weather data (Steiner et al., 1994). RWEQ computes standing and flat residue decomposition separately, and gives credit to standing residues in reducing erosion. This may explain why erosion estimates with RWEQ are consistently lower than with WEQ. As field length increased, WEQ estimates increased and RWEQ estimates decreased. The reason for the difference is the erosion mechanics illustrated in Figures 1 and 2.

Winter Wheat + Fallow

The winter wheat + fallow systems for Montana, Wisconsin, Missouri and Indiana were provided by Gary Tibke, and a similar system was developed for Colorado by Dr. Sutherland . Comparisons of the estimated erosion with RWEQ and WEQ permit the testing of climatic, soil texture, and field size influences. The agreement between estimated erosion ($kg/m^2/yr$) with RWEQ and WEQ was good for 805 meter or larger fields, but for narrow strips the agreement was poor.

$$WEQ = -0.092 + 0.422 RWEQ \quad r^2 = 0.406 \qquad [2]$$

For narrow strips, the WEQ computes much lower soil losses than RWEQ. Reports of accumulation of eroded material in the upwind edge of standing stubble in strip cropping systems after several years[†] suggest that soil erosion occurs across narrow strips for highly erodible soils. For large fields WEQ estimates higher erosion because of its unlimited transport capacity (Fig. 1). Also, for regions with annual rainfall > 800 mm (Wisconsin, Missouri, and Indiana) WEQ estimates less soil erosion because of the soil wetness and wind speed routine in the climatic factor. The effect of 6-meter tall trees was more pronounced with RWEQ than WEQ. Without trees, RWEQ estimated 4 times more erosion in Montana than WEQ, but with trees, RWEQ estimated almost half as much erosion as WEQ. RWEQ estimated a 92% reduction in erosion with trees, and WEQ estimated a 28% reduction. In Wisconsin, the reduction with trees was 95% with RWEQ and 17% with WEQ.

Continuous Sorghum

For section-size fields in continuous no-till sorghum, WEQ estimated soil losses of 10.31 $kg/m^2/yr$ for soils with an I = 300. RWEQ estimated soil losses of 0.65 $kg/m^2/yr$. With the residue decomposition routine in RWEQ, little of the sorghum stubble falls down before the sorghum is planted no-till in the spring. With WEQ the planner must estimate the quantity and status of standing stubble throughout the year. There is no tillage in the continuous sorghum so the differences between RWEQ and WEQ erosion estimates reflects the way the two models describe the erosion process and the management of surface residues. Standing residues were more effective with RWEQ than with WEQ.

Sorghum + Cotton

Multi-year rotations of sorghum and/or cotton and estimates of erosion with WEQ were provided by Monty Dollar for a matrix of soil erodible fractions. With RWEQ it is possible to compute the same erodible fraction with various combinations of sand, silts, organic matter, and calcium carbonate. This may be responsible for part of the difference between estimated erosion with RWEQ and WEQ. The clay and organic matter content impact changes in roughness decay which influence estimated soil erosion. The agreement between erosion estimates ($kg\ m^{-2}\ yr^{-1}$) with RWEQ and WEQ was good for large fields but was poor for those systems with narrow fields because of the difference in science within the models.

$$WEQ = 2.92 + 0.225\, RWEQ \quad r^2 = 0.118 \qquad [3]$$

Cropping Systems for the Southeast

Erosion estimates from systems including corn, cotton, tobacco, tomatoes, and watermelons were provided by Gene Hardee from South Carolina. The WEQ climatic factor varied from 2 to 7 and the soils were highly erodible. The comparison between estimated erosion ($kg/m^2/yr$) with RWEQ and WEQ was

$$WEQ = 0.264 + 0.0457\, RWEQ \quad r^2 = 0.277 \qquad [4]$$

These estimates were not statistically correlated. These typical systems in the Coastal Plains of South Carolina may experience considerable crop damage by sand blast injury. Farmers commonly use narrow wind strips to protect specialty crops such as tomatoes, watermelons, and onions from damage by blowing sand. The crop damage from soil blowing is much greater than would be expected based on estimates of wind erosion with WEQ[‡]. Transport mass estimates with RWEQ are sufficient to destroy most sensitive crops.

COMPARISONS OF ALL SYSTEMS

All of the RWEQ and WEQ erosion estimates for the various systems were combined. The resulting regression equation was

$$WEQ = 3.273 + 0.213\, RWEQ \quad r^2 = 0.249 \qquad [5]$$

These results show no statistical correlation between erosion estimates from RWEQ and WEQ for numerous management systems and climatic regions. Major differences are evident in high rainfall regions where WEQ erosion estimates are extremely low. For narrow fields WEQ estimates less erosion than RWEQ and for large fields WEQ estimates more erosion. Both conditions are included in field measurements of erosion and the field measurements do not support WEQ.

[†] Personal communication with Dr. W.D. Kemper.

[‡] Personal communication with Gene Hardee.

CONCLUSIONS

The science in RWEQ describes the wind erosion process and the wind erosion potential for areas with annual rainfall from 191 to 915 mm. The agreement between measured erosion from 15 sites and estimated erosion with RWEQ were highly significant (r^2 = 0.927). Erosion estimates with WEQ were very low in high rainfall regions and high in low rainfall regions. The correlation between measured erosion and estimated erosion with WEQ from the 15 sites was not significant (r^2 = 0.01).

The RWEQ science computes residue decomposition and decays soil roughness based on soil and climatic conditions. This reflects current field conditions and simplifies erosion computations. For most management systems, RWEQ erosion estimates reflects the importance of leaving residues stand as long as possible. Standing residues are 6 times more effective than the same quantity of residue flat on the soil surface.

The wind has a limited capacity to erode and transport soil material. Field measurements of transport mass revealed that the quantity of eroded material increases rapidly until 63% of the maximum transport capacity has been reached. As transport mass approaches the maximum capacity of the field and field lengths continue to increase, the average soil loss from the entire field must decrease. This is reflected in RWEQ science and illustrates that to minimize soil erosion within the field, field lengths must be considerably shorter than described by WEQ. Other options are to maintain residues in an erect position, minimizing tillage operations that bury surface residues, and combine residue management with soil roughening as the erosion hazard increases. For tillage to be effective in reducing wind erosion, more intensive management is required and tillage will not be effective in high rainfall regions.

Erosion control practices such as wind barriers, surface residues, and management practices have a major impact on wind erosion when the practices are used at the correct time at the proper location, and in a timely manner. Wind barriers in Montana and Wisconsin reduced estimated soil erosion with RWEQ by 90%, but only reduced estimated erosion 17 to 28% with WEQ.

The wind erosion control option that will be most effective depends on the climate, soil, and crop conditions and the management practices employed. With RWEQ, estimates of erosion will be much closer to measured values for any cropping system or climatic region of the country than estimates of erosion with WEQ. Estimates of erosion in the southeastern United States with RWEQ are sufficient to severely damage crops while erosion estimates with WEQ are consistently below 0.52 kg/m^2/yr.

REFERENCES

Bagnold, R.W. 1943. The physics of blown sand and desert dunes. London: Methuen.

Bondy, E., L. Lyles and W.A. Hayes. 1980. Computing soil erosion by periods using wind-energy distribution. J. Soil Water Conserv. 35: 173-176.

Chepil, W.S. 1957. Width of field strips to control wind erosion. Kan. Ag. Exp. Sta. Tech. Bull. No. 92.

Chepil, W.S. and N.P. Woodruff. 1963. The physics of wind erosion and its control. Adv. Agron. 15:211-302.

Fryrear, D.W. and A. Saleh. 1996. Wind erosion: Field length. Soil Sci. 161:398-404.

Fryrear, D.W., A. Saleh, J.D. Bilbro, H.M. Schomberg, J.E. Stout and T.M. Zobeck. 1998a. Revised Wind Erosion Equation (RWEQ). Wind Erosion and Water Conservation Research Unit. USDA-ARS, Southern Plains Area Cropping Systems Research Laboratory. Technical Bulletin No. 1

Fryrear, D.W., J.D. Bilbro, A. Saleh, H.M. Schomberg, J.E. Stout and T.M. Zobeck. 2000. RWEQ: Improved Wind Erosion Technology. J. Soil and Water Conserv. 55:183-189.

Greeley, R. and J.D. Iversen. 1985. Wind as a geological process on Earth, Mars, Venus and Titan. Cambridge University Press, Cambridge.

Lewis and Clark Expedition. 1806. Letter report sent to President Jefferson from Wallula, WA. April 27, 1806.

Lyles, L. 1983. Erosive wind energy distributions and climatic factors for the west. J. Soil Water Conserv. 38:106-109.

Malin, J.C. 1946. Dust storms, 1850-1900: Kansas Historical Quarterly 14:129-413.

Skidmore, E.L., P.S. Fisher and N.P. Woodruff. 1970. Computer equation aids wind erosion control. Crops and Soils. 22:19-20.

Skidmore, E.L. and R.G. Nelson. 1992. Small-grain equivalent of mixed vegetation for wind erosion control and prediction. Agron. J. 84:98-101.

Skidmore, E.L. and J. Tatarko. 1990. Stocastic wind simulation for erosion modeling. Tran. ASAE 33:1893-1899.

Skidmore, E.L. and N.P. Woodruff. 1968. Wind erosion forces in the United States and their use in predicting soil loss. USDA ARS Agriculture Handbook No 346, 42 pp, April, 1968.

Schomberg, H.M. and J.L. Steiner. 1997. Comparison of residue decomposition models used in erosion prediction. Agron. J. 89:911-919.

Steiner, J.L., H.M. Schomberg, C.L. Douglas and A.L. Black. 1994. Standing stem persistence in no-tillage small grain fields. Agron. J. 86:76-81.

USDA- Agricultural Research Service. 1961. A universal equation for measuring wind erosion. USDA-ARS. 22-69, 22pp, illus.

Woodruff, N.P. and D.V. Armburst. 1968. A monthly climatic factor for the wind erosion equation. J. Soil and Water Conserv. 23:103-104.

Woodruff, N.P. and F.H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Am. Proc. 29:602-608.