

Revised Wind Erosion Equation

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Abstract: The Revised Wind Erosion Equation (RWEQ) was developed at the request of the Natural Resource Conservation Service to replace the Wind Erosion Equation (WEQ). RWEQ incorporates new technology developed since WEQ was published in 1965. While the basic inputs are the same for the two equations, the form of the input data is considerably different. RWEQ can estimate erosion each day or for 365 days. Multi-year crop rotation systems can be input into RWEQ and modifications to the management system can be made to evaluate the most desirable farming system for each land manager. RWEQ is based on the assumption that the wind has a limited capacity to transport eroded material. As clean wind blows over an erodible surface, soil material will be emitted from the surface. The emission process will accelerate due to abrasive soil material accumulation as wind passes over the erodible soil. Initially the ability of the soil to emit eroded material will limit the increase in material being transported by the wind. As the wind approaches its maximum transport capacity, it is the ability of the wind to carry additional material that will limit increases in transport. This process has been observed, measured and is modeled in RWEQ. The technology in RWEQ emphasizes that to effectively control wind erosion and minimize land damage efficient wind erosion control practices must be in place over the entire field. When erosion does occur, soil losses are greatest within a few tens of meters of the upwind boundary. Measured annual soil losses at Crown Point, Indiana, were 31.21 kg m⁻², WEQ technology estimated 0.00 kg m⁻² erosion, and RWEQ estimated 25.24 kg m⁻² erosion. With the RWEQ technology, land managers can be confident that they can plan erosion control systems for their farmlands that will be effective. In addition, the wind barrier routine, hill effects, and field length equations will estimate erosion within the field and the quantity of material that will be leaving the downwind field boundary.

Key words: Wind erosion model, soil erosion, measured erosion, erosion prediction technology.

When the 1985 Food Security Act was enacted the only method for estimating soil erosion by wind was WEQ published in 1965 (Woodruff and Siddoway, 1965). WEQ was intended to provide a tool for comparing various conservation systems and estimating annual soil erosion. The 1985 Food Security Act required erosion estimates far beyond the intended use and capability of WEQ.

To correct the deficiencies of WEQ, the USDA Agricultural Research Service (ARS) wind erosion scientists were requested to develop a new wind erosion prediction system (WEPS) that would meet the needs of the Natural Resource Conservation Service (NRCS) and would be expandable to incorporate future technology. This major effort was initiated in 1986.

In 1991 the NRCS requested ARS to revise the WEQ. D.W. Fryrear was chairman of the task force for the revision and E.L. Skidmore, Co-Chairman. Efforts to revise WEQ (RWEQ) were to have minimal impact on progress towards completion of WEPS. Modeling approaches were outlined in 1992 and the framework for RWEQ was approved.

The basic foundation of RWEQ is Newton's Second Law of Motion. If the field control methods resist the force of the wind, there is no erosion. If control methods cannot resist the force of the wind, there will be erosion.

The RWEQ model estimates soil erosion with a minimum of input parameters. RWEQ is not intended to describe all of the physical parameters that may be factored in a specific field. RWEQ should not require detailed parameters not readily available to most land managers or technicians.

The crops data files available for RWEQ do not include all crops, but do contain the major crops where wind erosion is a significant problem. The mineral soils data files can be developed from physical property data. Organic or volcanic soils may require additional research efforts.

Weather data is critical for RWEQ. For the United States there are about 600 weather data sites. Additional sites are in operation and may be added to the weather data files currently in RWEQ. The program version of RWEQ is modular in design; therefore, improved equations can be incorporated into the model with minimal effort.

Objectives

The objective of RWEQ is to make scientifically defensible estimates of soil

erosion by wind for farming systems commonly used throughout the United States. These estimates are to be made using simple input data normally available for WEQ or for the Revised Universal Soil Loss Equation (RUSLE). RWEQ does not contain a separate routine for estimating quantities of PM-10 material because of the lack of field data to verify theoretical equations. RWEQ can be used to make erosion estimates for single days or for any time period including multi-year, multi-crop rotation systems. As with any model, major improvements were made between the first trial release in 1994 and the final release in May, 1998. Because of these changes, running erosion estimates with RWEQ versions released before RWEQ-97 may provide different answers than RWEQ-97.

The objective of this chapter is to provide a brief description of the parameters and the techniques used to verify the completed RWEQ model. As a final comparison, estimates of soil erosion with RWEQ and WEQ using the same basic input data are presented.

Parameters

RWEQ requires expression for weather, soils, crops, tillage, barriers, and hills.

Weather factor (WF)

The RWEQ model requires accurate weather data. In RWEQ-97 the 602 monthly weather data files include expressions of wind velocity, wind direction, rainfall, solar radiation, air temperature, and snow cover. Wind is the basic driving force. Bagnold (1943) and Zingg (1953) used the friction wind speed cubed to describe the relationship between wind speed and mass transported.

To compute the friction wind speed the roughness of the surface must be described. Since soil roughness, residue level, wind barriers and soil texture are highly variable the wind speed at the height of 2 meters above the immediate surface boundary was used.

The expression for wind speed includes a term for threshold speed.

$$W = \sum_{I=1}^N U_2 (U_2 - U_t)^2 \quad \dots 1$$

where,

W = wind value, $(m \text{ sec}^{-1})^3$

U_2 = wind speed at 2 meters, $m \text{ sec}^{-1}$

U_t = threshold wind speed at 2 meters
(assume $5 m \text{ sec}^{-1}$)

N = number of wind speed observations
(I) in a time period of 1 to 15 days.

In the RWEQ weather data files, the wind is described with Weibull coefficients k and c, per cent calm, and the cumulative probability distribution (Skidmore and Tatarko, 1990). The RWEQ program divides the 0 to 0.999 probability values into 500 uniformly distributed probability values. These probability values are used with the Weibull coefficients and per cent calm to compute 500 wind speeds for each management period. The 10 m wind speeds are converted to their equivalent 2-meter wind speeds, then the wind factor (Wf) is computed. The total wind factor for each period is determined by dividing the total wind value for each period by 500 (number of observations) and multiplying by the number of days in the period.

$$Wf = \frac{W}{500} \times N_d \quad \dots 2$$

where,

Wf = wind factor, $(m \text{ sec}^{-1})^3$,

W = wind value, $(m \text{ sec}^{-1})^3$, and

N_d = number of days in the period.

The number of time in the period N_d determines the time base for the weather factor WF. The force of the wind may be counterbalanced by the addition of water or snow to the soil surface. To include soil wetness and snow cover, terms were added to the wind factor with corrections for air density and gravity.

$$WF = Wf \frac{\rho}{g} (SW) SD \quad \dots 3$$

where,

WF = weather factor, $kg \text{ m}^{-1}$,

Wf = wind factor, $(m \text{ sec}^{-1})^3$,

ρ = air density, $(kg \text{ m}^{-3})$,

g = acceleration due to gravity, $m \text{ sec}^{-1} \text{ sec}^{-1}$,

SW = soil wetness, dimensionless, and

SD = snow cover factor.

The wetness of the soil surface influences the wind speed required to erode the soil (Chepil, 1956; Saleh and Fryrear, 1995). The soil surface will remain wet until the evaporative demand of the atmosphere dries the soil. Soil movement within minutes of a rain or irrigation on sandy or silt loam soils have been observed. The soil wetness factor developed for RWEQ-97 is:

$$SW = \frac{ET_p - (R + I) \frac{R_d}{N_d}}{ET_p} \quad \dots 4$$

where,

SW = soil wetness factor,

ET_p = potential relative evapotranspiration, mm,

R_d = number of rainfall or irrigation days
 $R+I$ = rainfall or irrigation,

mm, and
 N_d = number of days in period
 (normally 15).

There are many methods of computing ET_p , but for RWEQ97 the method reported by Samani and Pessarakli (1986) is used.

$$ET_p = 0.00162 \left(\frac{SR}{58.5} \right) (DT + 17.8) \quad \dots 5$$

where,

SR = total solar radiation for time period,
 cal cm^{-2} , and

DT = average temperature, $^{\circ}C$.

If there is more rain/irrigation than solar radiation can evaporate in the time period, then the soil wetness factor is zero and there is no erosion. With no rainfall/irrigation, the soil wetness factor is 1.0 for that period regardless of the previous period's condition. Soil wetness can be a major factor in some regions and during rainy periods. To test the soil wetness factor the 1990 erosion period from January 5 to May 31 at Big Spring, Texas, was used. The soil surface was flat and soil roughness and residue levels did not change for several weeks. There were 30 rainfall events that wet the soil

20.0 $kg\ m^{-2}$. With corrections for soil wetness the estimated erosion with RWEQ-97 was 17.1 $kg\ m^{-2}$.

The snow cover factor is equal to 1 minus the probability of a snow depth greater than 25.4 mm. Monthly snow probability values are in the weather data files. If the soil surface is covered with 25.4 mm of snow the SD = 0 and there is no erosion. If 50% of the time the soil is covered with snow the SD = 0.5 and the WF is 50% of the normal WF without snow.

Soil factors (EF, SCF)

The soil is the source of erodible material detached and transported by wind. Any soil surface is erodible if the wind speed is high enough, but for most soils the erodible fraction is that portion of the surface soil that is smaller than 0.84 mm in diameter as determined by standard compact rotary sieve (Chepil, 1962). Using the standard sieve and sampling the same soil site for 36 months, the following equation was developed to estimate the erodible fraction (EF) of mineral soils from soil property data:

$$EF = \frac{29.09 + 0.31 Sa + 0.17 Si + 0.33 Sa/Cl - 2.59 OM - 0.95 CaCO_3}{100} \quad \dots 6$$

where,

Sa = sand content, % (5.5 to 93.9),

Si = silt content, % (0.5 to 69.5),

SaCl = sand to clay ratio (1.2 to 53.0),

OM = organic matter, % (0.18 to 4.79), and

surface and 33 wind erosion events. The measured erosion was 18.6 $kg\ m^{-2}$. Without corrections in the wind factor for soil wetness the estimated erosion with RWEQ97 was

The range of soil property/ratio values in the data set are given in parenthesis. In RWEQ-97 the erodible fraction is considered a property of the soil and is

not changed. If data are available on changes in EF due to erosion or cropping systems, changes in EF can manually be made in the program.

When soils have been mechanically tilled the soil surface crust will be destroyed. If the tillage operation is performed when the soil profile is moist, there will usually be a range of nonerodible aggregates on the surface. If the soil surface is covered with nonerodible aggregates, erosion will be controlled except for very strong winds. As rainfall breaks down the nonerodible aggregates, a surface crust will form. For sandy soils this crust will result in an aerodynamically smooth surface with numerous sand particles on the surface. These sand particles can easily be moved by wind. For fine textured soils, as the nonerodible aggregates are broken down, a very dense smooth surface will result. Because of the bonding action of the fine soil particles, the crust formed will be nonerodible. The impact of a surface crust on soil erosion is expressed with a soil crust factor (SCF) (Hagen *et al.*, 1992). The SCF is computed with the equation:

$$SCF = \frac{1}{1 + 0.0066 (Cl)^2 + 0.021 (OM)^2} \quad \dots 7$$

where,

Cl = clay content, % (5.0 to 39.3),
OM = organic matter, % (0.32 to 4.74).

Rocks on the soil surface are treated as nonerodible elements that are not modified by rainfall.

In RWEQ-97 when rainfall/irrigation exceeds 12 mm since the last tillage operation, a soil crust factor is computed. Whenever clay content is less than 5% or immediately

after a tillage operation the SCF is set at one indicating that a crust is not impacting wind erosion.

Tillage roughness (K')

The roughness resulting from a tillage operation may be oriented (ridges and furrows) and/or random (soil clods). In addition to modifying surface roughness, tillage may flatten and bury crop residues (Nelson *et al.*, 1993). The surface roughness immediately after tillage depends on the implement used, residue levels, soil texture, soil moisture, and the previous tillage operation. Tillage roughness reduced soil erosion from 5.6 kg m⁻² for a smooth soil to 0.056 kg m⁻² for the same soil after a single listing operation (Chepil and Woodruff, 1954). Tillage roughness is not a suitable wind erosion control method for all regions of the country, all soils, or all management systems. In RWEQ-97 the effect of roughness on soil erosion is input with the relationships developed by Fryrear (1984) and Saleh and Fryrear (1999). Soil ridge roughness is computed with the equation

$$K_r = 4 \frac{(RH)^2}{RS} \quad \dots 8$$

where,

K_r = soil ridge roughness, cm,
RH = soil ridge height, cm, and
RS = soil ridge spacing, cm.

The roughness due to soil aggregates (clods) can be described by using training pictures, a pin meter (Potter *et al.*, 1990), or the chain method (Saleh, 1993). In RWEQ-97 the random roughness is measured using the chain method because it is simple and can be used by land managers. The chain reading is converted to the Allmaras

et al. (1966) random roughness index (RR) using the equation

$$RR = 0.0573 C_{rr}^{1.355} \quad \dots 9$$

where,

C_{rr} = chain random roughness

RR = random roughness index.

As the wind blows over the soil surface it will encounter the combined effect of both random and ridge roughness. The combined ridge and random roughness is computed using

$$K' = e^{1.86 K_{rmod} - 2.41 K_{rmod}^{0.934} - 0.124 C_{rr}} \quad \dots 10$$

where,

K' = soil roughness factor,

K_{rmod} = $R_c (K_r)$ which corrects K_r to wind angle when, and

R_c = rotational coefficient calculated from (Saleh, 1994).

$$R_c = 1 - 0.00032A - 0.000349 A^2 + 0.00000258 A^3 \quad \dots 11$$

where,

A = wind angle (0 if perpendicular, 90 if parallel), degrees.

The degradation of soil aggregate roughness was computed using rainfall amount and intensities. In RWEQ-97 the degradation of soil ridge roughness was computed for any soil using percent clay, percent organic matter, cumulative rainfall, and cumulative storm erosivity index.

$$ORR = e^{[DF(-0.025(CUMEI^{0.31}) - 0.0085(CUMR^{0.567}))]} \quad \dots 12$$

where,

ORR = ratio of K_r after rainfall to K_r before rainfall,

CUMEI = cumulative storm erosivity index, MJ-mm (ha-h)⁻¹, and

CUMR = cumulative rainfall, mm

DF = decay factor

where the decay factor is computed as

$$DF = e^{[0.934 - 0.07C1 + 0.0011(C1^2) - 0.674OM + 0.12(OM^2)]} \quad \dots 13$$

To decay soil random roughness a separate equation is used:

$$RRR = e^{[DF(-0.0009 CUMEI - 0.0007 CUMR)]} \quad \dots 14$$

where,

RRR = ratio of C_{rr} after rainfall to C_{rr} before rainfall.

Crop factors (SLR_f x SLR_s x SLR_c = COG)

The quantity and orientation of crop residues in the field can have a significant impact on soil erosion by wind (Chepil, 1944; Englehorn *et al.*, 1952; Fryrear and Armbrust, 1968; Siddoway *et al.*, 1965; Skidmore *et al.*, 1966). To quantify the effect of crop residues on wind erosion, the fraction of the soil surface covered with nonerodible plant material, the plant silhouette from standing plant residues, and growing crop canopies are used (Bilbro and Fryrear, 1994).

In RWEQ-97 the effect of flat residues (any lying on the soil surface) is described with a soil loss ratio coefficient (SLR_f) that was developed from numerous field and laboratory wind tunnel studies. SLR_f is estimated from the decomposition routine or per cent soil cover can be input if residues are added to a field. The equation used to convert flat cover to SLR_f is

$$SLR_f = e^{-0.0438(SC)} \quad \dots 15$$

where,

SLR_f = soil loss ratio coefficient for flat cover, and

SC = soil surface covered with flat residues, %.

Standing plant residues reduce the wind speed close to the soil surface. Laboratory wind tunnel studies on number, height, and diameter of standing material have been summarized into a soil loss ratio coefficient (SLR_s) (Bilbro and Fryrear, 1994). To determine the silhouette area, the height (harvest height), diameter, and number of standing stalks in a square meter are used.

$$SLR_s = e^{-0.0344(SA^{0.6413})} \quad \dots 16$$

where,

SLR_s = soil loss ratio for plant silhouette

SA = silhouette area computed by multiplying the number of standing stalks in 1 m^2 times average diameter (cm) times stalk height (cm).

Average stalk height can be estimated from harvest height of the crop. If stalks are leaning after a tillage operation, the height of the stalk above the ground is used, and not the total length of the stalk.

After crops are harvested the stubble or residue remaining in the field will begin to decompose. The standing stubble will rot at the base of the plant and flat residue will decay. The rate of decomposition will depend on the temperature and number of rainy-days. In RWEQ the method published by Schomberg and Steiner (1997) is used. Because not all regions produce the same

quantity or quality of residue, economic yield, plant population (plant or head number), crop height at harvest, and harvest height should be regionally adjusted. Within the program these parameters are used to estimate above-ground residue and to partition residue mass into standing and flat pools. Based on the routines suggested by Schomberg and Steiner (1997) the per cent soil cover is calculated using

$$SC = 100 \left[1 - e^{-mcf (M_f)} \right] \quad \dots 17$$

where,

SC = per cent soil cover,

M_f = flat residue mass kg m^{-2} , and

mcf = mass cover conversion factor.

Emerging crop seedling and subsequent growing plants provide a partial canopy cover over the soil. Field data have been collected on canopy cover and days after planting for several crops. To convert crop canopy to soil loss ratio the following equation is used:

$$SLR_c = e^{-5.614(cc^{0.7366})} \quad \dots 18$$

where,

SLR_c = soil loss ratio for growing crop canopy

cc = fraction of soil surface covered with crop canopy.

The soil loss ratio for a crop canopy is not used unless green living plants are in the field. The development of a crop canopy is initiated with a planting operation in the management input file. It is possible for ground cover, plant silhouette, and crop canopy to be present in the field at the same time.

Wind barriers

Wind barriers, hedges, or shelter belts are used in areas where erosive winds are from a single direction during the wind erosion season. Before RWEQ wind barriers were assumed to protect a distance downwind equal to ten times the height of the barrier. In RWEQ the protected distance is a function of wind velocity, barrier density, barrier height, and the roughness of the soil surface. The method of describing the effect of wind barriers on leeward wind speeds was developed by J.D. Bilbro from analysis of published data (Sturrock, 1969, 1972):

$$PUV = 100e^{-(OD)^{0.423} (DD)^{-1.098}} \quad \dots 19$$

where,

- PU = per cent of upwind speed
 OD = optical density (range from 28 to 100%)
 DD = distance downwind in barrier heights, H.

The OD can now be computed for multirow-multidensity barriers using the equivalent optical density procedure (Fryrear *et al.*, 2000b). The limitations are no PUV greater than 100 and protected distances no greater than 30 times the barrier height.

Hills

Not all fields are flat, so a method of describing the impact of a hill is included in RWEQ. Slope gradient and length are used to describe the hill. RWEQ assumes the hill extends perpendicular to the wind and the upwind toe of the hill is the windward edge of the field.

The equation to describe the wind speed over a hill was adapted from Queney (1948). His equation was designed to estimate wind

over low, gently sloping, smooth-profiled, narrow mountains where the effects of the earth's rotation and tropopause are negligible and the height does not exceed 10% of the base. The equation to compute the 2 m high wind speed at various points along the slope is

$$U(x) = U \left[1 + \left[\frac{H_H x a}{a^2 + (x')^2} * \frac{a^2 - (x')^2}{a^2 + (x')^2} \right] \right] \quad \dots 20$$

where,

$U(x)$ = 2-meter wind speed at distance x from upwind edge of field, m sec^{-1} ,

U = open 2-meter high wind speed for flat surface, m sec^{-1} ,

H_H = height of hill, m,
 or $H_H = S$ divided by $\sin \alpha$

a = characteristic $\frac{1}{2}$ width of hill which is $\frac{1}{2}$ distance from toe of hill to peak, m or $a = \cos \alpha$ ($\frac{1}{2} S$),

x' = horizontal distance from center of hill, m, or $x' = x - x_h$

α = angle of slope, degrees,

S = slope length, m,

G = slope gradient or $G = \tan \alpha = H_h/x_h$,

x = distance from upwind edge of field, m, and

x_h = distance from edge of field to center of hill, m.

Vertical Distribution of Eroded Material

After a sampler was designed that could collect material being transported by the wind

at various heights (Fryrear, 1986) a procedure had to be developed for summarizing the vertical distribution data. Using published data and the numerous field data, Fryrear and Saleh (1993) used two equations to describe the vertical distribution of eroded material. An exponential equation was used to describe the relationship between quantity of material and height for surface creep and saltating material. This equation will have a specific quantity at a height of zero. Based on field data the collected quantity at a height between zero and 3 mm is very close to the integrated quantity of the exponential equation between zero and 3 mm height. This is the quantity of eroded material moving in surface creep. On log-linear graph paper this portion of the mass is a straight line.

To describe the quantity between saltation height and 2 meters a power expression is used. This agrees with expressions used by Nickling (1978) and Zingg (1953). Additional samples have been collected to a height of 15 m to verify that the power expression is correct (Chen and Fryrear, 1996). The upper point where the power and exponential equations meet is the height used for integrating purposes. Adding the quantities from integrating the exponential and power equations gives the total mass being transported at that point. The field data collected for various field lengths supports that the wind has a limited capacity to transport eroded material.

Maximum Transport Capacity

The heart of any wind erosion model is the equation for computing the mass transport of wind eroded material. Mass transport varies with soil texture, soil surface

conditions, field length, and climatic conditions (Fryrear and Saleh, 1996; Stout and Zobeck, 1996). Transport equations have been developed and applied to the movement of agricultural soils (Gregory and Borelli, 1986; Stout, 1990; Hagen and Armbrust, 1994), desert sands, and wind-blown snow (Greeley and Iversen, 1985). One common feature of these equations is the assumption that the horizontal flux is proportional to the difference between the maximum transport capacity and the actual transport at a point within the field. The basic equation that defines the horizontal distribution of transport mass is

$$b(x) \frac{dQ(x)}{dx} + Q(x) - Q_{\max}(x) + S_r(x) = 0 \dots 21$$

where,

$Q(x)$ = mass transport at downwind distance x , kg (meter-width)⁻¹,

$Q_{\max}(x)$ = maximum transport, kg (meter-width)⁻¹,

$S_r(x)$ = surface retention coefficient,

x = distance from the upwind edge of the field, m, and

$b(x)$ = field length scale, m.

For the special case where Q_{\max} and "b" are constant, this equation will result in the sigmoidal form:

$$\frac{Q(x)}{Q_{\max}} = 1 - e^{-\left(\frac{x}{s}\right)^2} \dots 22$$

From this sigmoidal form when $x = s$ ("s" is critical field length), $Q(s) = 63.2\%$ of Q_{\max} . The sigmoidal form was used to statistically analyze the field data from nine erosion events. The erosion events were selected because information was available on soil erodible fraction, soil surface roughness, crop residue levels, wind speed

and direction every minute, and essential climatic data on rainfall, temperature, humidity and solar radiation. From these nine events empirical equations were developed to compute the maximum transport capacity (Q_{\max}) and critical field length "s" using a weather factor SLR_f , SLR_c , SLR_s soil roughness, erodible fraction, and soil crust. The equation for Q_{\max} is

$$Q_{\max} = 109.8 (WF \times EF \times SCF \times K' \times COG) \quad \dots 23$$

and for critical field length "s" is

$$s_{\max} = 150.71 (WF \times EF \times SCF \times K' \times COG)^{-0.3711} \quad \dots 24$$

The empirical coefficients for Q_{\max} and "s" for these nine events were then used to compare measured and estimated soil mass transport for over 200 erosion events and for the entire erosion period at each site. With RWEQ the transport mass is considered as that material from the soil surface to a height of 2 m. For large fields there may be clouds of dust hundreds of meters high. Calculations of the quantity of material that may be present in these clouds compared to the portion within 2 m of the soil surface show that typically over 90% of the total mass in a cloud 2000 meters high will be contained within 2 m of the soil surface.

Computing Average Soil Loss from Mass being Transported

As field transport mass data (kg (m-width)^{-1}) were collected at various points within the eroding field the question arose concerning what these data represented. The assumption was made that the transport mass at a point represented the eroded material

from a one-meter wide strip to the upwind field boundary. To compute soil erosion from mass transport data, the mass being transported at a specific point is divided by the upwind field length. The result is the average soil loss for the entire upwind field expressed as kg m^{-2} . By increasing field length, the relationship between field length and soil erosion can be determined.

For RWEQ the relationship between transport mass, soil loss, and field length are illustrated in Fig. 1. For this specific field the maximum transport mass in $180 \text{ kg (m-width)}^{-1}$ and the maximum soil loss is 0.86 kg m^{-2} at a field length of 86 m. Once the wind has reached its maximum transport capacity, if the field length increases, the average soil loss from the upwind field must decline.

The RWEQ technology says that the major damage within the field will occur close to the point called critical field length "s". Between the point "s" and the upwind field boundary the capacity of the soil to emit erodible material will limit the increasing transport. Downwind of "s" it is the remaining capacity of the wind to transport material that limits the increasing transport. To prevent land damage one must protect the upwind edge of the field. Wind barriers must be spaced closer than the critical field length to be effective.

Comparison of Measured and Estimated Erosion using RWEQ

RWEQ is a combination of empirical and process models and is the first wind erosion model extensively tested under field conditions within and outside the Great Plains. Sixteen erosion periods from seven states, sand contents of 25 to 84%, clay

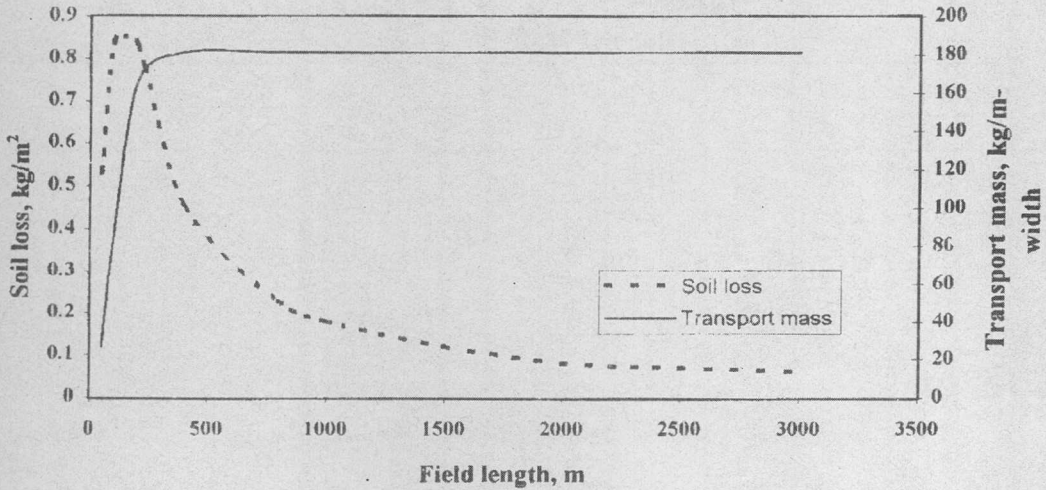


Fig. 1. RWEQ-estimated average soil loss and estimated transport mass as a function of field length

contents of 5 to 32% and organic matter contents of 0.20 to 1.60% were selected. Annual rainfall varied from 356 to 915 mm and elevation from 216 to 1341 meters. The sites, erosion period and measured erosion are listed in Table 1. The correlation between measured erosion and estimated erosion with RWEQ was $r^2 = 0.90$. If good input data are available, RWEQ will provide estimates that agree with measured values.

Considering the number of computation required to produce the measured and estimated values of erosion this correlation is highly significant. When all 51 site years are included the comparison between measured and estimated erosion using RWEQ was:

$$\text{RWEQ SL} = 0.982 \times \text{Measured SL} \quad R^2 = 0.805$$

where,

RWEQ SL = soil loss estimates using the RWEQ model (Fryrear *et al.*, 2000a).

The regression coefficient of 0.982 is very close to 1.00, and the intercept is zero; therefore, the agreement was consistent for the entire range of values (0.00 to 31.21 kg m^{-2} for measured, and 0.00 to 39.15 kg m^{-2} for RWEQ).

Comparison of Measured and Estimated Erosion using WEQ

A comparison of measured erosion and estimated erosion using WEQ was made using the same sixteen sites where RWEQ was tested. Time periods varied from 3 months to 12 months. The estimates with WEQ were made using the best management period techniques currently used by NRCS. The largest differences were for Prosser, Washington (measured = 0.32 and WEQ estimate = 29.13 kg m^{-2}) and for Crown Point, Indiana (measured = 31.21 and WEQ estimate = 0.00 kg m^{-2}). The WEQ estimates were not correlated to measured data $R^2 = 0.016$. The deviation between measured

Table 1. Measured soil erosion and estimated soil erosion with the wind erosion equation (WEQ) and the Revised Wind Erosion Equation (RWEQ) for 15 sites

| Site | Periods | Soil Erosion (kg m ⁻²) | | |
|-------------------|--------------------------|------------------------------------|-------|-------|
| | | Measured | WEQ | RWEQ |
| Mabton, WA* | 12 Dec. 90 to 28 Apr. 91 | 3.68 | 7.01 | 3.85 |
| Prosser #1 WA | 3 Dec. 91 to 25 Mar. 92 | 0.17 | 0.58 | 0.25 |
| Prosser #2 WA | 10 June 92 to 15 June 93 | 0.32 | 29.13 | 1.05 |
| Sidney, NE | 31 Oct. 90 to 7 May 91 | 2.29 | 0.11 | 5.65 |
| Elkhart, KS | 4 Dec. 91 to 15 Apr. 92 | 12.86 | 25.35 | 16.09 |
| Eads, CO | 30 Oct. 90 to 7 May 91 | 2.43 | 4.30 | 2.76 |
| Akron, CO | 27 Oct. 88 to 26 May 89 | 0.83 | 4.98 | 6.59 |
| Akron, CO | 25 Oct. 89 to 29 Apr. 90 | 1.10 | 3.03 | 0.38 |
| Portales, NM | 24 Nov. 94 to 6 Apr. 95 | 0.01 | 21.52 | 0.13 |
| Crown Point, IN | 01 Jan. 90 to 30 Dec. 90 | 31.21 | 0.00 | 25.24 |
| Martin County, TX | 24 Jan. 95 to 5 Jul. 95 | 0.30 | 5.47 | 0.63 |
| Martin County, TX | 11 Jan. 95 to 23 May 95 | 0.80 | 5.47 | 1.01 |
| Martin County, TX | 24 Jan. 95 to 5 Jul. 95 | 0.30 | 10.82 | 0.92 |
| Plains, TX E | 13 Dec. 94 to 24 May 95 | 2.20 | 7.69 | 0.54 |
| Plains, TX B | 13 Dec. 94 to 24 May 95 | 1.60 | 8.09 | 1.39 |
| Big Spring, TX* | 10 Jan. 90 to 4 June 96 | 20.96 | 7.42 | 18.60 |

* Sites with erosion events used to calibrate RWEQ.

and estimates with WEQ reflect the concern in 1985 of USDA wind erosion scientists that WEQ erosion estimates are questionable outside the Central Great Plains region. The climatic factor of WEQ does not reflect the influence of high and low rainfall amounts on soil erosion. Also, the fact that average soil loss with WEQ does not decline as the wind reaches its maximum transport capacity illustrates that this basic assumption with WEQ is in error. For soil loss to remain constant (Fig. 2) the transport capacity must grow without limit, and this phenomena does not agree with measured field data or new transport science.

Limitations of RWEQ

Because of the empirical relationship used to determine the parameter functions, RWEQ should not be used beyond the parameter limits under which it was developed and tested. For example, the erodible fraction of mineral soils is determined using per cent sand, clay, organic matter, and calcium carbonate. For organic soils the OM values may exceed 80% and the equation used to compute erodible fraction will not be suitable.

Describing the wind flow pattern over complex topographies such as those in South Central Washington state will require a much

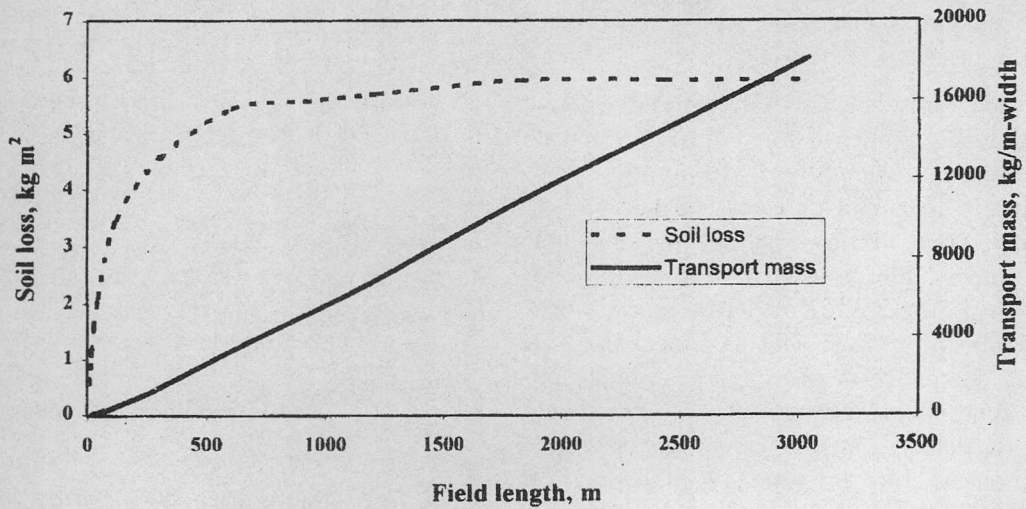


Fig. 2. WEQ-estimated average erosion and transport mass as a function of field length.

more complex hill model than RWEQ. The estimates of very fine airborne material, commonly called PM₁₀, is not attempted because of the lack of field verification data.

Research is continuing to improve the expressions that describe the effects of weathering on soils and on plant residues. Additional weather data sets should be included into RWEQ as soon as possible. A critical evaluation of all weather data should be conducted to eliminate erroneous data sets.

Conclusions

The field-tested wind erosion model RWEQ has been available since 1998 and it will accurately estimate soil losses due to wind erosion. The model includes parameters for climate, soils, crops, and management effects. The RWEQ model can be used for single wind erosion event, weekly, monthly, or annual estimates of erosion. The RWEQ design is simple and logical, i.e.,

if there is no wind there is no erosion. If the soil is covered with snow or water there is no erosion. If the soil is covered with nonerodible material there is no erosion. If the soil is highly erodible and erosive winds occur there will be erosion. The magnitude will depend on the type and variety of control methods in place.

RWEQ enables operators to test the effect of various tillage methods, crop rotations, wind barriers, hills, or management options such as irrigation on wind erosion. RWEQ will provide estimates of mass being transported, so the protection needed to insure the survival of crop seedlings can be determined.

The RWEQ model will provide data on the most erodible areas within a field and where deposition will occur. With the addition of multi-row barrier density data, the land manager can determine the number and spacing of rows within a wind barrier, barrier

orientation, and the spacing between barriers to protect his fields.

Plant residues are extremely important in many wind erosion control systems. However, residues will decompose very quickly in humid climates and because of limited rainfall, sufficient quantities may not be produced to protect the soil in semi-arid regions. The RWEQ model will show when residues are insufficient to protect the soil and alternative methods must be employed to control wind erosion. Alternative methods may include soil roughening, cover crops, wind barriers, or irrigation. With the RWEQ model the land manager can quickly evaluate various methods and select the method that is most adaptable to their operation.

Whatever erosion control method is used the land manager can be confident that the erosion estimates will be very close to measured values if the field were instrumented.

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