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6. THE WIND EROSION COMPONENT OF EPIC

George V. Cole and Leon Lyles

ABSTRACT

The basic concept of soil flux integration is reviewed to show how it has guided the adaptation of the Wind Erosion Equation for use in the EPIC model. The major integration problems involved summing short-term, continual soil losses to give 1 day's soil loss. The adaptation is reviewed and the results of some numerical data are compared.

INTRODUCTION

The Wind Erosion Equation, which was developed to predict annual average soil loss associated with a single crop (Skidmore 1976, Skidmore and Woodruff 1968, Woodruff and Siddoway 1965), was adopted for use in EPIC. The adaptation was needed because in simulating the long-term effects of soil loss due to wind- and water-induced erosion, EPIC computes at a daily rate and considers multiple crops per year. The Wind Erosion Equation (WEE), therefore, had to be adapted so that (1) soil loss would be expressed in metric tonnes per (hectare.day) rather than tons per (acre.year), (2) it would simultaneously handle a growing crop and residues from previous crops, and, most importantly, (3) it would compute soil losses for 1-day rather than 1-year intervals.

In the following sections, the basic structure of the WEE is reviewed as an aid to comprehending the modifications used in adapting the equation for use in EPIC. For a more comprehensive review see Cole et al. (1982). The modifications are then discussed and, finally, some numerical results from typical EPIC simulations are analyzed.

WIND EROSION

General Concepts

WEE was developed originally as a prediction and design tool to estimate soil loss and the effects of various conservation practices in reducing soil loss. Consequently, the units of measurement were chosen to be grasped easily. For example, since soil loss is cyclic with a yearly period, the unit of a year was a natural choice.

The variable chosen to express soil loss, E, has the units of soil loss flux. However, since it is defined as a potential average annual soil loss (Woodruff and Siddoway 1965), E represents the temporal and spatial average of f, the "point" flux. E cannot vary in the interval of 1 year or over the space of a given field. It can only vary according to five factors: I, K, C, L, and V (all symbols are defined in the "Notations" section of this chapter). Actually, these factors are functions of other variables. Because E is an average flux in space and time, we have the following for an erodible rectangular field of area A and duration T:

$$m = \int_T \int_A f(x,y,t)dx\ dy\ dt \qquad [6.1a]$$

and

$$E = m/(AT) \qquad [6.1b]$$

The geometry for any such rectangular field of area A (A = lw) is depicted in figure. 6.1. For any other geometry, a different functional relationship would exist for E. The implication is that a different wind erosion equation would be required for each shape; e.g., WEE is not adequate for a circular field. However, since A and T are contained in the limits of integration of equation 6.1a and the divisor of equation 6.1b, the same f would apply for any shape or duration.

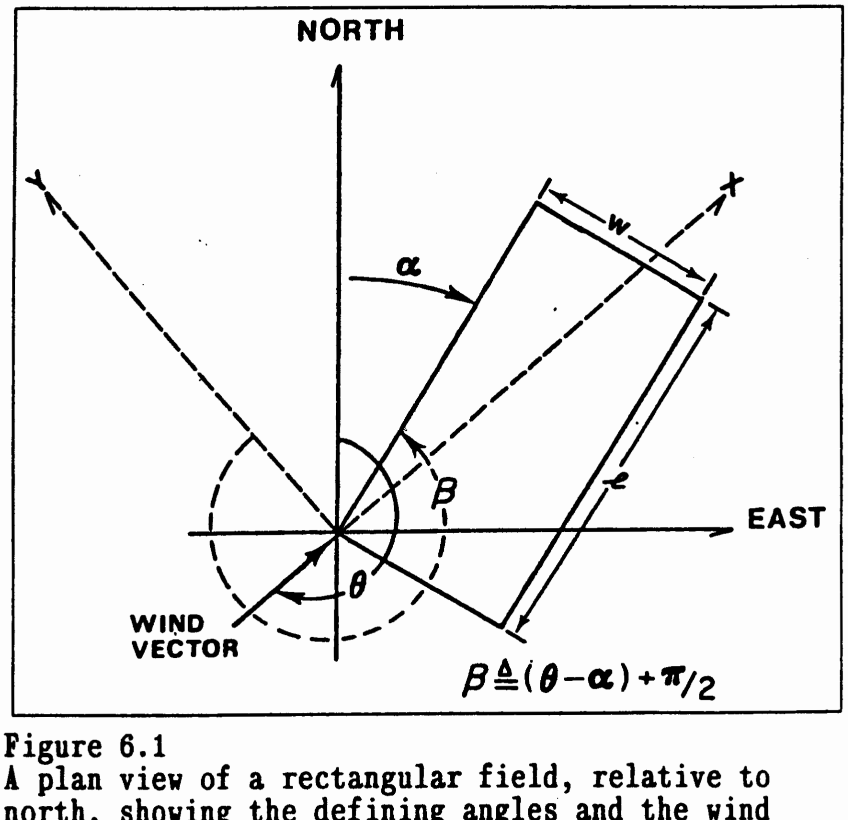

Figure 6.1
A plan view of a rectangular field, relative to north, showing the defining angles and the wind reference coordinate system.

Woodruff and Siddoway (1965) and Skidmore and Woodruff (1968) imply that

$$E = f_2[V, f_3(IK, IKC, L)] \quad [6.2]$$

Since equations 6.1b and equation 6.2 are equivalent, there must exist a relationship similar to equation 6.1a such that

$$m = \int_T \int_A f_4(\hat{V}, \hat{I}, \hat{K}, \hat{C}, x) dx\ dy\ dt \quad [6.3]$$

where all or some of the independent variables are functions of space and/or time. The use of the caret on the factor implies that if an independent variable is present in equation 6.2, then some unknown functional form must exist at the flux level, i.e., f_4, for each factor.

Modifications

The major problem in adapting the wind erosion equation for use in EPIC is the unavailability of f_4. In its place we must use its integrated form, i.e., equation 6.2. In this section we describe the method to accomplish this, along with the method of accounting for the time and space variations of the factors that affect soil loss.

EPIC provides the framework to sum the effects of the various factors that affect soil loss and, hence, productivity. From the point of view of soil loss by wind, loss is equivalent to the sum of the daily soil loss surface density. This sum is expressed analytically by rearranging equation 6.1 into

$$E = \frac{1}{AT} \int_T \int_y q\ dy\ dt \quad [6.4]$$

where

$$q \triangleq \int f dx \quad [6.5]$$

Rearranging Eq. [6.4] results in

$$E_{EPIC} = \frac{1}{T} \sum_{i=1}^{n} \left[\frac{1}{A} \int_{\Delta t_i} q\ dt\ dy \right] \quad [6.6]$$

where the bracketed quantity represents the daily soil loss per unit area (m_i''), and T the simulation period.

The modifications of WEE must produce the equivalent of the daily soil loss surface density shown in brackets in equation 6.6. EPIC sums for n days, where n is chosen prior to simulation. In equation 6.6 the order of integration of t and y is the reverse of that in equation 6.4. This reversal implies that the q as computed does not change during the day; i.e., it is a daily average. This assumption then restricts the y integration for a fixed wind angle (θ), which results in a simple computation of L, since there is only one integration over the field in the y direction for 1 day.

The problem of inputs changing during the period of computation has been simplified but not changed. Variables such as I, K, and V can now be considered essentially constant for a single day; but L will change, since θ and u change on a shorter time scale than EPIC's computation iteration period of 1 day. Hence, we are faced with converting q to some daily average value. This is similar to the problem Chepil faced; i.e, how to convert from short-time, essentially continuous relative soil loss with fixed input variables to absolute soil loss for a year (Chepil 1960). Here we have to convert from short-term soil losses to 1 day's rather than 1 year's soil loss, but the problem remains, since the description of the wind variable that drives soil loss still fluctuates considerably during 1 day.

The justification for using a daily average is based on an argument used in calculus, i.e., that a sum based on finite increments becomes exactly equal to the integral as the increment approaches zero. Here then, we claim that long-term calculations of soil loss based on daily averages will approach that based on the original experimental short-term data more closely than a single calculation for 1 year.

The above argument presupposes that q is available! This is hardly so, as noted by Cole et al. (1982). What is needed, then, is a relationship which when applied to E would approximate the integration of q for 1 day, yielding "daily E".

The best available function that approximates this desired function involves a single multiplication factor that Bondy et al. (1980) called the erosive wind energy factor. They used a monthly factor to subdivide E, while allowing the I, K, L, and V factors to take on values for the periods under consideration. We extended their concept by shortening the period of interest from month to a single day.

The assumption that soil loss is directly proportional to erosive wind energy is implied by equation 6.7 which computes period average soil loss flux, i.e.,

$$E_i = r_i E \qquad [6.7]$$

where r_i is the erosive wind energy factor for the ith period. If E has units of tonnes per (hectare.year), then E_i has units of tonnes per (hectare.day).

To utilize equation 6.7 with equation 6.6 requires that m_i be determined, i.e.,

$$m_i'' = \Delta t_i E_i$$

However, since Δt_i in EPIC is 1 day, both variables are numerically equal; and, consequently, E_i can be summed as if it were m_i''.

The erosive wind energy factor is calculated as

$$r_i = e_i / \sum_{i=1}^{n} e_i \qquad [6.8]$$

where

$$e_i \triangleq \int_{\Delta t_i} \dot{W} dt \qquad [6.9]$$

or equivalently,

$$e_i = c_i \langle u_e^3 \rangle_i \Delta t_i \qquad [6.10]$$

equation 6.10 is derived from equation 6.9 by expressing the work rate W, in terms of the steady state form of the first law of thermodynamics, i.e.,

$$\dot{W} = \begin{cases} \dot{P} - Q & u > u_t \\ 0 & u \leq u_t \end{cases} \qquad [6.11]$$

where

$$P = \int_{A_3} \tau_{zx} (z) u(z) dx\, dy \qquad [6.12]$$

and $\dot{Q}$ is zero for all $u > u_t$. Equation 6.12 expresses the total power flow into a rectangular control volume that represents the boundaries of a one-dimensional fluid-flow soil-loss system.

For application in EPIC, equations 6.7, 6.8, and 6.10 are used, with the index i representing the ith day and the upper limit n in equation 6.8 representing the number of days in a year. The daily value of $\langle u_e{}^3 \rangle$ is computed by using a regression equation relating it to $\langle u \rangle$. This regression equation was developed from the following two equations, assuming that the daily windspeed is distributed as a two parameter Weibull distribution, p, i.e.,

$$\langle u_e{}^3 \rangle = \int_{u_t}^{\infty} u^3 p(u,k,c)du; \qquad k \triangleq 2 \qquad [6.13]$$

and

$$c \triangleq 1.12\langle u \rangle \qquad [6.14]$$

Equation 6.13 is derived from the standard definition of the third moment of the distribution, p. For erosive wind, the integration is for all values greater than the threshold value, u_t. Figure 6.2 illustrates how these modifications (and those that follow) fit into the EPIC's wind erosion submodel.

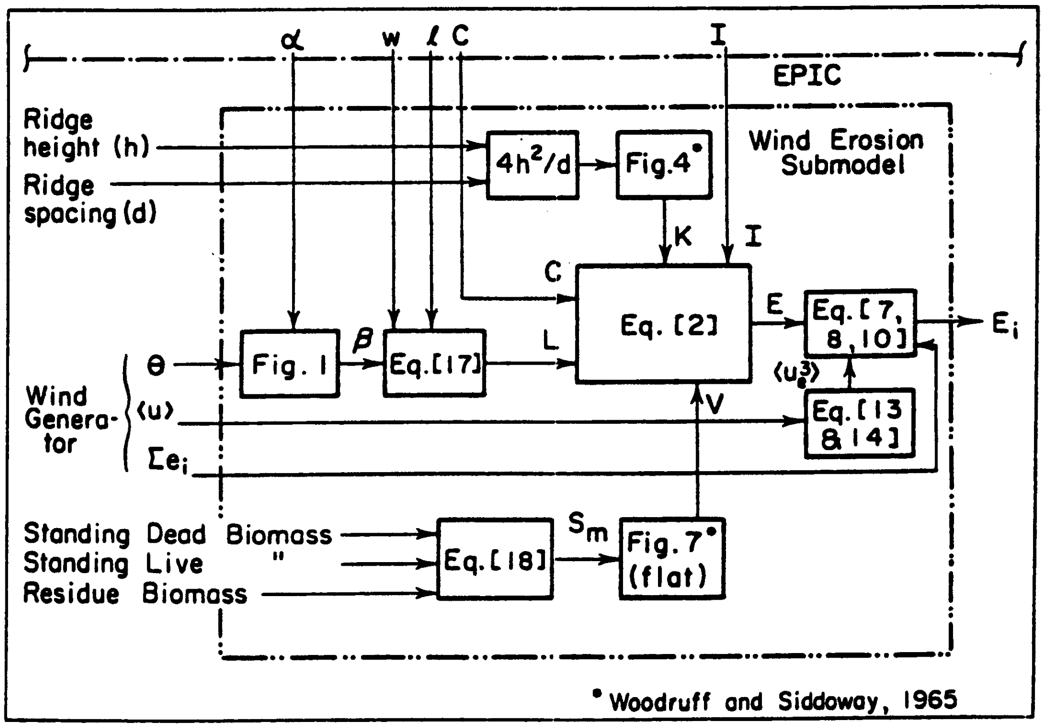

Figure 6.2
Block diagram of the wind erosion submodel and its interfaces within EPIC.

Having now dealt with the time integration of q in equation 6.6, the integration with respect to y must be considered. If, as in the previous argument, we claim that the application of the erosive wind energy factor approximates the removal of the integration from E, we might also attribute to it the capability of removing the crosswind or y component of integration. An alternate hypothesis involves the use of a single worst L, by Chepil et al. (1964), i.e.,

$$L = w \sec A; \qquad 0^{\circ} < A < 85^{\circ} \qquad [6.15]$$

where A is defined as the angle between side w of the field and the positive x axis and is called the prevailing wind erosion direction. Because they used this L, the value of E would imply a rectangular field of width w and length L that is aligned on the L side with the average wind vector. Here again, L is independent of y. In other words, the effect of varying L into E was desired and was accomplished external to VEE.

To properly incorporate the effect of varying L with y would require integration of equation 6.7 over y for each day or equivalently for each field angle β. This integration would be equivalent to perhaps 10-20 computer solutions of equation 6.7 per time step, depending on the size of Δy.

By adopting a scheme to select "an L" that yields the "correct answer," one can reduce the number of computations. This is, in essence, what Chepil et al. (1964) implied by his worst case estimate and also what Skidmore (1965) implied by his time weighting concept. Because neither approach appears to be founded upon actual integration of q with respect to y, it appears that any reasonable scheme that satisfies

$$0 < L < (\ell^2 + w^2)^{1/2} \qquad [6.16]$$

would be an adequate approximation. We selected an average of the chords as they vary in y, which for a rectangular field of l and w oriented at β is

$$L = \frac{\ell w}{w \,|\cos\beta| + \ell\,|\sin\beta|} \qquad [6.17]$$

While equation 6.17 is arbitrary, it does satisfy the criteria of equation 6.16 and is simple to compute.

Finally, we come to the method used in EPIC to simultaneously simulate the effects of a growing crop and residue from a previous crop. Due to the paucity of mixture data, a modification of the method of Lyles and Allison (1980) was proposed. That is,

$$S_m = \sum_{i=1}^{n} P_i S_{it} \qquad [6.18]$$

where

$$P_i = R_i / \sum_{i=1}^{n} R_i \qquad [6.19]$$

$$\sum_{i=1}^{n} P_i = 1 \qquad [6.20]$$

and S_{it} s the grain equivalent for crop i (Lyles and Allison 1980), based on the total mixture weight. S_m (equation 6.18) is a weighted sum that satisfies the following two criteria:

$$(S_{it})_{min} \leq S_m \leq (S_{it})_{max} \qquad [6.21]$$

and

$$S_m \rightarrow S_k; \qquad i = 1, 2, \ldots k, \ldots n \qquad [6.22]$$

as

$$P_k \rightarrow 1. \qquad [6.23]$$

However, based on the further simplifying assumption that S_i is linear, the actual implementation in EPIC in a simple sum of S_i.

SIMULATION RESULTS

No measured data sets of erosion amounts are available for validating EPIC modifications of WEE. Using representative soils, crop rotations, and management operations for various States in the Midwest, Great Plains, and West, we compared 50 years' estimates of erosion amounts as simulated by EPIC and WEE according to current procedures (Bondy et al. 1980). We chose 10 counties to give geographic coverage and various crop rotations common to those counties (table 6.1).

Table 6.1
Wind erosion estimated by EPIC and WEE for selected crop rotations and locations in the United States

Comparison run No.	Crop rotation sequence[1]	Location: County, State	Soil[2]	Av. estimated soil loss: EPIC[3]		Av. estimated soil loss: WEE
				t/(ha.yr)[4]		
1.	Corn-soyb	Auglaize, OH	Keene SiL	0.1	±0.1	0.1
2.	Corn-soyb	Auglaize, OH	Keene SiL	0.8	±0.4	1.3
3.	Corn	Harrison, IA	Ida SiL	[5] 0.3	±0.3	2.8
4.	Corn	Harrison, IA	Ida SiL	[5] 2.4	±.7	2.6
5.	Corn-soyb	Monona, IA	Luton SiC	[5] 1.1	±0.5	3.4
6.	Corn-soyb	Monona, IA	Luton SiC	9.2	±4.6	11.5
7.	Whet-whet-falo	McLean, ND	Williams L	[5] 0.0	±0.0	0.4
8.	Whet-whet-falo	McLean, ND	Williams L	[5] 2.6	±2.4	9.8
9.	Whet-falo	Bennett, SD	Keith SiL	[5] 1.3	±2.0	0.7
10.	Whet-falo	Lyman, SD	Promise C	1.4	±2.4	1.1
11.	Whet-falo	Lyman, SD	Promise C	8.7	±9.3	3.2
12.	Whet-falo	Cheyenne, NB	Alliance SiL	0.2	±1.2	0.0
13.	Whet-corn-falo	Red Willow, NB	Keith SiL	3.5	±2.4	1.9
14.	Whet-corn-falo	Red Willow, NB	Keith SiL	4.7	±3.0	1.9
15.	Corn (irr)	Sherman, KS	Keith SiL	[5] 9.2	±1.8	4.3
16.	Grsg (irr)	Finney, KS	Carwile FLS	101.1	±10.3	24.2
17.	Grsg-falo	Finney, KS	Carwile FLS	125.1	±23.1	120.2
18.	Whet-grsg-falo	Stevens, KS	Vona SL	28.2	±20.1	18.1
19.	Whet	Carson, TX	Pullman CL	[5] 4.7	±4.3	1.0
20.	Whet-grsg-falo	Deaf Smith, TX	Pullman CL	31.8	±26.9	34.6
21.	Cotn-grsg	Bailey, TX	Amarillo FSL	119.1	±25.4	130.6
22.	Cotn	Bailey, TX	Amarillo FLS	165.8	±26.9	199.4
23.	Cotn	Gaines, TX	Patricia FS	741.6	±117.7	581.2
24.	Whet-falo	Prowers, CO	Baca Cl, Wiley SiL	3.9	±2.7	0.2
25.	Cotn-cotn-grsg	Quay, NM	Pullman L	54.4	±14.7	47.3
26.	Whet-alfa-alfa	Curry, NM	Amarillo FSL	41.7	±19.0	5.6
27.	Oats-oats-alfa alfa-alfa	Churchill, NV	Tipperary S	22.2	±11.5	8.8

[1] Soyb = soybeans, whet = wheat, falo = fallow, grsg = grain sorghum, irr = irrigated, cotn = cotton, alfa = alfalfa.

[2] SiL = silt loam, SiC = silt clay, L = loam, C = clay, FSL = fine sandy loam, SL = sandy loam, CL = clay loam, S = sand.

[3] 50-year average.

[4] + - 1 standard deviation.

[5] 49-year average.

Agreement between EPIC and VEE was excellent for 17 comparison runs, fair for 7, and poor for 3. Possible reasons for differences between the two methods of estimating wind erosion include

1. EPIC has residue decomposition equations that are applied daily. In VEE, an average overwinter residue loss, usually 15 to 30 %, is applied at the end of winter in the rotation.

2. Simplified forms of the small-grain equivalent equation are used in EPIC, while the original equations are used in solving VEE.

3. Simulated wind data are used in EPIC. Actual long-term average data are used in VEE.

4. A daily L factor is applied in EPIC, whereas a weighted approach by period is used to determine L for application in VEE.

The large difference between the estimates for run 16 is apparently due to EPIC's use of two shredding operations to simulate grazing by cattle (table 6.1). The crop residue reductions appear larger than would be expected from cattle grazing the grain sorghum leaves after harvest. Runs 26 and 27 indicate some problem in EPIC's simulation of dry matter production during establishment and early growth of perennial crops--in these runs, alfalfa.

For 8 runs, 49-year averages of estimates by EPIC are reported because the first-year erosion estimates were incompatible with the other 49 estimates (table 6.1). These first-year anomalies may have been due to the fact that crop residue conditions prior to the starting date of the simulations were ignored.

These comparisons between EPIC and VEE are a check on procedures for determining factor values between the two methods and not a validation of EPIC. Biomass production (excluding grain) has a major impact on wind erosion estimates. We used 50-year average biomass outputs of EPIC in solving VEE. Consequently, values in table 6.1 are not realistic, unless EPIC accurately predicts dry matter production.

NOTATIONS

Symbol		Definition and Dimensions[1]
A	=	area of the erodible field, L^2, or the angle between w and the positive x axis (dimensionless)
A_3	=	top surface of a control volume for the soil loss system (L^2)
C	=	climatic factor (dimensionless)
c	=	parameter for function p (L/T)
c_1	=	a constant
d	=	ridge spacing (L)
E	=	potential average annual soil loss ($M\ L^{-2}T^{-1}$)
e_i	=	erosive wind energy for the ith period ($M\ L^2T^{-2}$)
f	=	the normal component of the net soil flux vector along the ground surface ($M\ L^{-2}T^{-1}$)
f_i	=	a function, i an an integar subscript used to differentiate between functions.
h	=	ridge height (L)
I	=	soil erodibility ($M^{-2}T^{-1}$)
K	=	soil ridge roughness (dimensionless)
k	=	kth value of an index or parameter for function p (dimensionless)
L	=	field length, a function (L)
ℓ	=	larger dimension of a rectangular field (L)
m	=	soil loss (M)
m''	=	soil loss per unit area (M/L^2)
n	=	upper limit of an index (dimensions vary)
P	=	Power into soil loss system ($M\ L^2T^{-3}$)
P_i	=	proportion of R_i in mixture (dimensionless)
p	=	a Veibull probability density function (T/L)
Q	=	energy loss from soil loss system as heat ($M\ L^2T^{-2}$)
q	=	integral of f along x within the limits of the field ($M\ L^{-1}T^{-1}$)
R	=	biomass (surface) density, dry weight of vegetative cover per unit area (M/L^2)
r_i	=	erosive wind energy factor for the ith period (dimensionless)
S	=	small grain equivalent, small grain biomass surface density (M/L^2)
T	=	time interval, on the order of 1 year (T)
t	=	time, T, or metric tonnes (M)
u	=	wind velocity (L/T)
u_e	=	erosive wind velocity (L/T)
u_t	=	threshold velocity, the wind velocity below which no soil moves (L/T)

V = equivalent quantity of vegetative cover (M/L^2)

W = work done in moving soil ($M\ L^2T^{-2}$)

w = small dimension of a rectangular field (L)

WEE= Wind Erosion Equation

x = distance along the field in the wind direction (L)

y = distance perpendicular to x and z (L)

z = distance perpendicular to x and y (L)

α = the field angle relative to north, clockwise positive (dimensionless)

β = the field angle relative to the wind, counterclockwise positive from the positive y axis (see fig. 6.1) (dimensionless)

Δ = difference operator (dimensionless)

θ = the direction of the wind vector relative to north, clockwise positive (dimensionless)

π = Pi, 180° (dimensionless)

τ_{zx}= shear stress on z plane in x direction ($M\ L^{-1}T^{-2}$)

Subscripts

i = index

k = kth value of an index

m = mixture

t = total

Superscripts and other symbols

n = upper limit of index (dimensions vary)

$\hat{}$ = careted variable is time and/or space dependent

$\cdot$ = implies variable is a time rate of change

$\langle\ \rangle$ = enclosed function is an average with respect to an interval

$\triangleq$ = defined

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[1]M, L, T refer to the dimensions of mass, length and time.

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