89-39-B

# 19

# Modified EPIC Wind Erosion Model

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A model proposed by Woodruff and Siddoway (1965), titled a wind erosion equation, has been used extensively with various modifications during the past quarter century. The model was developed as a result of investigations to understand the mechanics of the wind erosion process, to identify major factors influencing wind erosion, and to develop wind erosion control methods. The general functional relationship between the dependent variable, $WE$ (the potential average annual soil loss), and the equivalent variables or major factors is

$$WE = f(I, WK, WC, WL, VE) \quad [1]$$

where $I$ is soil erodibility index, $WK$ is soil ridge-roughness factor, $WC$ is a climatic factor, $WL$ is the unsheltered median travel distance of wind across a field, and $VE$ is equivalent vegetative cover. These factors will be discussed in more detail later.

The solution of the wind erosion equation yields the expected amount of erosion from a given agricultural field. A second application of the equation involves specifying the amount of erosion that can be tolerated and then solving the equation to determine conditions (i.e., amount of residue, field width, etc.) to limit soil loss to the specified amount. The equation has been used widely for both of these applications.

The USDA Soil Conservation Service has used the equation extensively to plan wind erosion control practices (Hayes, 1966). Hayes (1965) also used the equation to estimate crop tolerance to wind erosion. The equation also is a useful guide to wind erosion control principles (Carreker, 1966; Moldenhauer & Duncan, 1969; Woodruff et al., 1972). Other uses of the equation include: (i) determining spacing for barriers in narrow strip-barrier systems (Hagen et al., 1972); (ii) estimating fugitive dust emissions from agricultural and subdivision lands (PEDCO, 1973; Wilson, 1975); (iii) predicting horizon-

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*Modeling Plant and Soil Systems*—Agronomy Monograph no. 31.

tal soil fluxes to compare with vertical aerosol fluxes (Gillette et al., 1972); (iv) estimating effects of wind erosion on productivity (Lyles, 1975; Williams et al., 1984); (v) delineating those croplands in the Great Plains from which various amounts of crop residues may be removed without exposing the soil to excessive wind erosion (Skidmore et al., 1979); and (vi) estimating the erosion hazard in a national inventory (USDA, 1989).

Solving the functional relationships of the wind erosion equation as presented by Woodruff and Siddoway (1965) required the use of tables and figures. The awkwardness of the manual solution prompted a computer solution (Fisher & Skidmore, 1970; Skidmore et al., 1970) and later the development of a slide-rule calculator (Skidmore, 1983). The computer solution not only predicted average annual soil loss, but solved the Woodruff and Siddoway (1965) equation to determine field conditions necessary to reduce potential erosion to a tolerable amount. It also allowed the user to look at many combinations of wind erosion control practices for particular field and climatic conditions.

The model has been adopted for use with personal computers (Halsey et al., 1983) and interactive programs (Erickson et al., 1984). Cole et al. (1983) adapted the Woodruff and Siddoway (1965) model for simulating daily wind erosion soil loss as a submodel in the erosion productivity impact calculator (EPIC) developed by Williams et al. (1984). The latter version, which was simplified by fitting equations to the figures of Woodruff and Siddoway (1965), with additional modifications, is described in this presentation.

The Woodruff and Siddoway (1965) wind erosion model was converted from annual to daily prediction to interface with EPIC. However, two variables, soil erodibility ($I$) and climatic factor ($WC$), remained constant for each day of the year. The other variables were subject to daily variation as simulated by EPIC. In this adaption, the user will supply variable inputs for accounting periods, most likely monthly.

## I. MODEL DESCRIPTION

### A. Soil Erodibility Index

Soil erodibility can be estimated by standard dry sieving and use of Table 19-1. Using sieving results assumes that the percent of soil aggregates >0.84 mm characterize a soil's aggregate status during the erosion period. In current practice, erodibility is often estimated by grouping soils, often according to predominant textural class (Table 19-2).

If the average percentage of dry soil fractions >0.84 mm is 24, the corresponding soil erodibility index from Table 19-1 is 197 Mg/ha.

### B. Ridge Roughness Factor

The ridge-roughness factor estimates the fractional reduction of erosion caused by ridges of nonerodible aggregates. It is influenced by ridge spacing and height, and is defined relative to a 1:4 ridge height to ridge spacing ratio.

Table 19-1. Soil erodibility *I* for soils with various percentages of nonerodible fractions as determined by standard dry sieving (Woodruff & Siddoway, 1965).

| | Percentage of dry soil fractions >0.84 mm | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tens | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | Mg/ha | | | | | | | | | |
| 0 | -- | 695 | 560 | 493 | 437 | 404 | 381 | 359 | 336 | 314 |
| 10 | 300 | 294 | 287 | 280 | 271 | 262 | 253 | 244 | 238 | 228 |
| 20 | 220 | 213 | 206 | 202 | 197 | 193 | 186 | 182 | 177 | 170 |
| 30 | 166 | 161 | 159 | 155 | 150 | 146 | 141 | 139 | 134 | 130 |
| 40 | 126 | 121 | 117 | 114 | 112 | 108 | 105 | 101 | 96 | 92 |
| 50 | 85 | 80 | 75 | 70 | 65 | 61 | 56 | 54 | 52 | 49 |
| 60 | 47 | 45 | 43 | 40 | 38 | 36 | 36 | 34 | 31 | 29 |
| 70 | 27 | 25 | 22 | 18 | 16 | 13 | 9 | 7 | 7 | 4 |
| 80 | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Table 19-2. Descriptions of wind erodibility groups (WEG) (Soil Conservation Service, 1988).

| WEG | Predominant soil texture class of surface layer | Dry soil aggregates >0.84 mm | Wind erodibility index (*I*) |
|---|---|---|---|
| | | % | Mg/ha |
| 1 | Very fine sand, fine, sand, or coarse sand | 1 | 695 |
| | | 2 | 560 |
| | | 3 | 493 |
| | | 5 | 404 |
| | | 7 | 359 |
| 2 | Loamy very fine, sand, loamy fine sand, loamy sand, loamy coarse sand, or sapric soil materials | 10 | 300 |
| 3 | Very fine sandy loam, fine sandy loam, sandy loam, or coarse sandy loam | 25 | 193 |
| 4 | Clay, silty clay, noncalcareous clay loam, or silty clay loam with more than 35% clay content | 25 | 193 |
| 4L | Calcareous loam and silt loam, or calcareous clay loam, and silty clay loam | 25 | 193 |
| 5 | Noncalcareous loam and silt loam with less than 20% clay content, or sandy clay loam, sandy clay, and hemic organic soil materials | 40 | 126 |
| 6 | Noncalcareous loam and silt loam with more than 20% clay content, or noncalcareous clay loam with less than 35% clay content | 45 | 108 |
| 7 | Silt, noncalcareous silty clay loam with less than 35% clay content and fibric organic soil material | 50 | 85 |
| 8 | Soils not susceptible to wind | >80 | 0 |

$$KR = \frac{4HR^2}{IR} \qquad [2]$$

where $KR$ is the ridge roughness (mm), $HR$ is the ridge height (mm), and $IR$ is the ridge interval (mm). The ridge-roughness factor is a function of ridge roughness as expressed by the equations

$$WK = 1.0, KR < 2.27 \qquad [3]$$

$$WK = 1.125 - 0.153 \ln(KR), 2.27 \leq KR < 89 \qquad [4]$$

$$WK = 0.336 \exp(0.00324\, KR), KR \geq 89 \qquad [5]$$

### C. Climatic Factor

Chepil et al. (1962) proposed a climatic factor to determine average annual soil loss for climatic conditions other than those occurring when the relationship between wind tunnel and field erosion was obtained. It is an index of wind erosion as influenced by moisture content in surface soil particles and by average windspeed.

The windspeed term of the climatic factor was based on the rate of soil movement being proportional to average windspeed cubed (Bagnold, 1943; Chepil, 1945; Zingg, 1953). The soil moisture term was developed on the basis that erodibility of soil varies inversely with the square of equivalent water content in the near surface soil, which was assumed to vary with the Thornthwaite index (Chepil, 1956).

The climatic factor was expressed as

$$C = 386 \frac{\bar{u}^3}{(PE)^2} \qquad [6]$$

where $\bar{u}$ is the mean annual windspeed corrected to 9.1 m and *PE* is the Thornthwaite (1931) index. The value of 386 indexes the factor to conditions at Garden City, KS.

As the *PE* index gets small when precipitation is slight, as in arid regions, the climatic factor in Eq. [6] approaches infinity. In application, an upper limit was established by restricting minimum monthly precipitation to 13 mm (Lyles, 1983). The FAO (1979) modified the Chepil et al. (1962) index so that, as precipitation approaches zero, windspeed dominates the climatic factor. Conversely, as precipitation approaches potential evaporation, the climatic factor approaches zero. The influence of soil water in the FAO version is less than the squared influence of soil water demonstrated by Chepil (1956).

Skidmore (1986) proposed

$$CE = \rho \int_{R}^{\infty} (u^2 - R^2)^{3/2} f(u) du \qquad [7]$$

where

$$R = u_t^2 + \gamma'/\rho a^2, \qquad [8]$$

*CE* is wind-erosion climatic erosivity and is directly proportional to the mass flow rate of an all-erodible material, $\rho$ is air density, $u$ and $u_t$ are windspeed and threshold windspeed, respectively, $\gamma'$ is cohesive resistance of absorbed water, and $a$ is a combination of constants, $k/\ln(z/z_0)$. When $k = 0.41$, $z = 10$ m, and $z_0 = 0.05$ m, then $a = 0.0774$.

The value of $\gamma'$ is approximated by

$$\gamma' = 0.5\,\omega^2 \qquad [9]$$

where $\omega$ is equivalent soil-water content; fraction of water (by mass or volume) in the soil divided by fraction of water in the same soil at $-1500$ J/kg (Chepil, 1956; Skidmore, 1986). It was assumed that equivalent surface-water content was approximated by the ratio of precipitation to potential evaporation.

The windspeed probability density function, Eq. [7], may be expressed as the Weibull distribution

$$f(u) = (k/c)(u/c)^{k-1} \exp[-(u/c)^{k}] \qquad [10]$$

where $c$ and $k$ are scale and shape parameters, respectively. Parameter $c$ has units of velocity and $k$ is dimensionless (Justus et al., 1976; Apt, 1976). Weibull parameters have been determined from windspeed distribution summaries for many locations in the Great Plains (Hagen et al., 1980).

Equation [7] expresses wind power (W m$^{-2}$). When multiplied by the time duration in the accounting period represented by $f(u)$, it yields erosive wind energy. This is the energy of the wind in excess of that necessary to overcome threshold shear stresses represented by $R$. It indicates the time-average values for meteorological elements tendency to cause wind erosion. It accounts for the meteorological influence of both wind and precipitation. It also overcomes a threshold windspeed for surface particles. Thus, erosive wind energy becomes a useful parameter to evaluate climatic factor for the wind erosion equation. As the climatic factor in the wind erosion equation, the result of Eq. [7] must be converted to an annual basis and referenced to the standard (Skidmore, 1986).

Therefore, using the summation notation for evaluating Eq. [7]

$$WC = \frac{100}{GC} \sum_{U_{i+0.5} > R}^{n} (u_{i+0.5}^{2} - R)^{3/2}\,[F(u_{i+1}) - F(u_{i})] \qquad [11]$$

where $F(u_i)$ is the cumulative distribution function

$$F(u_i) = 1 - \exp[-(u_i/c)^{k}]. \qquad [12]$$

Choose an $n$ large enough so that $F(u_{n+1}) \approx 1.0$.

The notation $u_{i+0.5}$ refers to a windspeed midway between $u_{i+1}$ and $u_i$. $GC$ indexes $WC$ to reference conditions and has the value as calculated by Eq. [11] and using long-term climatic averages for Garden City, KS.

### D. Field Length

Originally, field length was considered as the length of a field in the prevailing wind erosion direction (Woodruff & Siddoway, 1965). However, sometimes almost as much wind occurs from one direction as from another, so there is essentially no prevailing wind erosion direction. In these cases, the preponderance of wind erosion forces in the prevailing wind erosion direction was used to assess equivalent field length (Skidmore & Woodruff, 1968; Skidmore, 1965). Later, from a more detailed analysis, tables were prepared that provide wind-erosion direction factors, numbers that when multiplied by field width, yield median travel distance. The factors are functions of preponderance of wind erosion forces in the prevailing direction and the deviation of prevailing wind erosion direction from perpendicular to the direction of field length (Skidmore, 1987).

In some of the modeling efforts, the procedure for determining $L$ for use in the wind erosion equation was simplified by ignoring wind direction distributions. Cole et al. (1983) suggested

$$WL = FW \sec\theta \quad WL \leq (FL^2 + FW^2)^{1/2} \qquad [13]$$

$$WL = WL \csc\theta \text{ in all other cases} \qquad [14]$$

where $FW$ and $FL$ are the small and large dimensions, respectively, of a rectangular field, and $\theta$ is the angle between side $w$ and the prevailing wind erosion direction. As $\theta$ varies through $\pi/2$ radians, $WL$ will range from $FW$ to $FL$ with a maximum equal to the main diagonal of the field. The procedure Williams et al. (1984) used in EPIC was

$$WL = \frac{(FL)(FW)}{FL\,\left|\cos\left(\frac{\pi}{2} + \theta - \phi\right)\right| + FW\,\left|\sin\left(\frac{\pi}{2} + \theta - \phi\right)\right|} \qquad [15]$$

where $FL$ is the field length (m), $FW$ is the field width (m), $\theta$ is the wind direction clockwise from north in radians, and $\phi$ is the clockwise angle between field length and north in radians.

## II. VEGETATIVE FACTOR

The value of crop residue for controlling wind erosion was recognized early (Chepil, 1944). Siddoway et al. (1965) quantified the specific properties of vegetative covers influencing soil erodibility. They also developed regression equations relating soil loss by wind to selected amounts, kinds, and orientation of vegatative covers, wind velocity, and soil cloddiness. Their studies led to the relationship developed by Woodruff and Siddoway (1965) showing the influence of an equivalent vegetative cover of small grain and sorghum [*Sorghum bicolor* (L.) Moench] stubble for various orientations (flat, standing) and heights, and then relating soil loss to equivalent vegetative cover.

Efforts to evaluate the protective role of additional crops have continued. Lyles and Allison (1980, 1981), in wind-tunnel tests, determined equivalent wind-erosion protection from selected range grasses and crop residue. They found high simple-correlation coefficients from an equation of the form

$$(SG)_e = aX^b \qquad [16]$$

where $(SG)_e$ is flat small-grain equivalent (kg/ha), $X$ is the quantity of residue or grass to be converted, and $a$ and $b$ are constants. Prediction equation coefficients are given in Tables 19–3 and 19–4.

It is not practical in testing all combinations of crops and residues to determine their protection value as flat small-grain equivalents. Therefore, a method is needed to estimate the protection values of crops and residues not tested.

Until recently, all small-grain equivalence data have been limited to dead crop residue or dormant grass. Armbrust and Lyles (1985) reported flat small-grain equivalents for five growing crops (corn [*Zea mays* L.], cotton [*Gossypium hirsutum* L.], grain sorghum, peanut [*Arachis hypogaea* L.], and soybean [*Glycine max* (L.) Merr]).

$$(SG)_e = a_1 \, Rw^{b_1} \qquad [17]$$

where $Rw$ is the aboveground dry weight of the crop to be converted (kg/ha), and $a_1$ and $b_1$ are constant coefficients for each crop. They found that if only rough estimates of $(SG)_e$ are needed, an average coefficient could be used. An average equation determined from pooling all crop data with rows running perpendicular to wind direction yielded 8.9 and 0.9 for $a_1$ and $b_1$, respectively.

Suppose we wish to know the equivalent, flat, small-grain residue for a field with grain sorghum growing in 400 kg/ha of flat-random winter wheat (*Triticum aestivum* L.) residue when the dry weight of the growing grain sorghum is 83 kg/ha and the grain sorghum is growing in rows perpendicular to the expected wind. In this case, the $(SG)_e$ for the growing sorghum Eq. [11] would be

$$(SG)_e = 8.9(83)^{0.9} = 475 \qquad [18]$$

and from Table 19–3 for the wheat residue

$$(SG)_e = 7.3(400)^{0.8} = 880. \qquad [19]$$

However, because of nonlinear relationships, the flat small-grain equivalents are not strictly additive. When more than one crop contributes to the residue, it is better to use a single equation of the form

$$(SG)_e = a_1^{p_1} \, a_2^{p_2} \, (Rwt)^{b_1 p_1 + b_2 p_2} \qquad [20]$$

where $p_1$ and $p_2$ are fractions of total residue, $Rwt$; $a_1$, $a_2$, $b_1$, and $b_2$ are constant coefficients for respective crops as in Eq. [11].

Table 19–3. Coefficients in the prediction equation, $(SG)_e = aR_w^b$, for conversion of crop residues to equivalent quantity of flat, small-grain residue (kg/ha) (Lyles & Allison, 1981).

| Crop residue | Surface orientation | Height | Length | Row spacing | Row orientation to flow | Prediction equation coefficients *a* | *b* | $r^2$ |
|---|---|---|---|---|---|---|---|---|
| | | cm | cm | cm | | | | |
| Winter wheat | Standing | 25.4 | -- | 25.4 | Normal | 4.306 | 0.970 | 0.997 |
| Rape† | Standing | 25.4 | -- | 25.4 | Normal | 0.103 | 1.400 | 0.990 |
| Cotton | Standing | 34.3 | -- | 76.2 | Normal | 0.188 | 1.145 | 0.998 |
| Sunflower | Standing | 43.2 | -- | 76.2 | Normal | 0.021 | 1.342 | 0.994 |
| Winter wheat | Flat random | -- | 25.4 | -- | -- | 7.279 | 0.782 | 0.993 |
| Soybean | Flat random | -- | 25.4 | -- | -- | 0.167 | 1.173 | 0.993 |
| Rape | Flat random | -- | 25.4 | -- | -- | 0.064 | 1.294 | 0.997 |
| Cotton | Flat random | -- | 25.4 | -- | -- | 0.077 | 1.168 | 0.998 |
| Sunflower | Flat random | -- | 43.2 | -- | -- | 0.011 | 1.368 | 0.993 |
| Forage sorghum | Standing | 15.9 | -- | 76.2 | Normal | 0.353 | 1.124 | 0.995 |
| Silage corn | Standing | 15.9 | -- | 76.2 | Normal | 0.229 | 1.135 | 0.998 |
| Soybean | 1/10 standing | 6.4 | -- | 76.2 | Normal | 0.016 | 1.553 | 0.991 |
| | 9/10 flat random | -- | 25.4 | -- | -- | | | |

† Rape (*Brassica rapa*), sunflower (*Helianthus annuus* L.).

Table 19-4. Coefficients in the prediction equation, $(SG)_e = aX^b$, for conversion of range grasses to equivalent quantity of flat, small-grain residue (kg/ha) (Lyles & Allison, 1980).

| Grass species† | Grazing management | Grass height | Prediction equation coefficients $a$ | $b$ | $r^2$ |
|---|---|---|---|---|---|
| | | cm | | | |
| Blue grama | Ungrazed | 33.0 | 0.60 | 1.39 | 0.98 |
| Buffalograss | Ungrazed | 10.2 | 1.40 | 1.44 | 0.97 |
| Big bluestem | Properly grazed | 15.2 | 0.22 | 1.34 | 0.99 |
| Blue grama | Properly grazed | 5.1 | 1.60 | 1.08 | 0.99 |
| Buffalograss | Properly grazed | 5.1 | 3.08 | 1.18 | 0.99 |
| Little bluestem | Properly grazed | 10.2 | 0.19 | 1.37 | 0.99 |
| Switchgrass | Properly grazed | 15.2 | 0.47 | 1.40 | 0.99 |
| Western wheatgrass | Properly grazed | 10.2 | 1.54 | 1.17 | 0.99 |
| Big bluestem | Overgrazed | 2.5 | 4.12 | 0.92 | 0.99 |
| Blue grama | Overgrazed | 2.5 | 3.06 | 1.14 | 0.99 |
| Buffalograss | Overgrazed | 1.5 | 2.45 | 1.40 | 0.99 |
| Little bluestem | Overgrazed | 2.9 | 0.52 | 1.26 | 0.99 |
| Switchgrass | Overgrazed | 2.5 | 1.80 | 1.12 | 0.99 |
| Western wheatgrass | Overgrazed | 2.5 | 3.93 | 1.07 | 0.99 |

† Blue grama (*Bouteloua gracilis*), buffalograss (*Buchloë dactyloides* [Nutt.] Engelm), big bluestem (*Andropogon gerardi* [Vitman]), little bluestem (*Andropogon scoparius* [Mich.], switchgrass (*Panicum virgatum*), and western wheatgrass (*Agropyron smithii* [Rybd.]).

Either the equivalent, flat, small grain or the vegetative factor is needed for the various procedures to estimate wind erosion. The relationship between equivalent, flat, small grain and vegetative cover was demonstrated graphically by Woodruff and Siddoway (1965). Williams et al. (1984) fit an equation to the graphical relationship to give

$$VE = 0.2533\ (SG)_e^{1.363}. \qquad [21]$$

## A. Model Execution

Several approaches to finding the solution are possible using graphs, figures, tables, slide rule, computer, etc. For this example, we will use the procedure presented by Williams et al. (1984). This procedure is done stepwise, but has been simplified computationally by fitting equations to the figures of Woodruff and Siddoway (1965). The first step (E1) is to determine soil erodibility, *I*. Steps E2 and E3 are determined by multiplying the value from the previous step by the ridge-roughness and climatic factors, respectively. Accounting for ridge roughness

$$\mathrm{E2} = (I)\ (WK) \qquad [22]$$

and climatic factor

$$\mathrm{E3} = (I)\ (WK)\ (WC). \qquad [23]$$

The inclusion of field length is

$$\mathrm{E4} = (WF^{0.348} + \mathrm{E3}^{0.348} - \mathrm{E2}^{0.348})^{2.87} \qquad [24]$$

where

$$WF = \mathrm{E2}[1.0 - 0.122(WL/WL_{o})^{-0.383} \exp(-3.33\ WL/WL_{o})] \quad [25]$$

and

$$WL = 1.56 \times 10^{6}(\mathrm{E2})^{-1.26} \exp(-0.00156\ \mathrm{E2}) \quad [26]$$

where $WF$ is a field length factor and accounts for the influence of field length on reducing erosion estimate, and $WL_o$ is maximum field length for the reducing wind-erosion estimate.

The role of equivalent vegetative cover is expressed by

$$\mathrm{E5} = \psi_1\ \mathrm{E4}^{\psi_2}. \quad [27]$$

Parameters $\psi_1$ and $\psi_2$ are functions of vegetative cover factor described by the equations:

$$\psi_1 = \exp(-0.759VE - 4.74 \times 10^{-2}\ VE^2 + 2.95 \times 10^{-4}\ VE^3) \quad [28]$$

$$\psi_2 = 1.0 + 8.93 \times 10^{-2}\ VE + 8.51 \times 10^{-3}\ VE^2 - 1.5 \times 10^{-5}\ VE^3 \quad [29]$$

where $VE$ is (Mg ha$^{-1}$) determined by Eq. [21].

The estimate from Eq. [27] represents the annual rate of expected erosion during the period represented by the climatic factor $WC$. To determine the expected soil loss during an accounting period, it is necessary to multiply the estimate from Eq. [27] by the fraction of the year occurring during the accounting period.

## III. SUMMARY

The EPIC version of the wind erosion model is presented with two major modifications. In EPIC, soil erodibility and climatic factor are held constant for each day of the year. Soil erodibility is calculated at the start of each year using the soil textural triangle. In this modified version, the soil erodibility as influenced by tillage, weather, crop, etc. may be input by the user for subyearly accounting periods. Similarly, a climatic factor may input for each accounting period. The soil loss during each subyearly accounting period is calculated for the conditions (values of equivalent variables or major factors) representative of the accounting period and summed to obtain a yearly soil loss.

The other major modification is the method for calculating the climatic factors. The former method, which gave an inordinately large value when precipitation was low, was replaced with a more physically based procedure. Both methods yield the same values for the Garden City, KS reference.

## A. Verification

The fundamental relationship between soil loss and independent variables is that proposed by Woodruff and Siddoway (1965). Continued research has furnished equivalent vegetative cover information for additional crops and crop residues (Lyles & Allison, 1980, 1981; Armbrust & Lyles, 1985). A major limitation is the uncertainty in the conversion of relative field erodibility to annual soil loss and that this conversion is developed for average annual soil loss rather than individual wind storms.

## B. Research Needed

Research is needed and in progress (Hagen, 1988) to develop submodels to furnish the values of input variables in time and space. These variables include: surface soil wetness; distributions of leaf and stem silhouette; biomass of residue in standing, flat, and buried categories; soil surface configuration; aggregate size distribution; and stability. A wind simulator is needed that provides friction velocity and wind direction at subhourly intervals on specified surfaces, separated various distances from the weather station that furnished the data base for the simulator.

More research is needed to formulate and verify soil-loss flux equations that are sensitive to changing values of input variables during individual wind storms. Additional development is needed to determine soil-, climate-, and crop-specific conservation tillage and residue management systems that are most cost effective for sustaining productivity and protecting the environment.

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