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Computing soil erosion by periods using wind-energy distribution

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ABSTRACT: A new procedure for computing wind erosion by periods, based on erosive wind-energy distribution, closely parallels the procedure for computing water erosion using the universal soil loss equation. Monthly erosive wind energy has been determined for 76 locations in the Great Plains. These data can be used to estimate erosion by crop-stage periods or other periods in question using the wind erosion equation. Use of the procedure is described for typical crop sequences of winter wheat-fallow at Garden City, Kansas, and spring wheat-spring wheat-fallow at Minot, North Dakota. Advantages and disadvantages of the new procedure and additional research needs are identified also.

WIND erosion is a serious problem in many areas of the United States. Extensive physical damage occurs annually in the Great Plains and West and to a lesser extent in the Great Lakes Region, the Eastern Coastal Plain, and on muck and peat soils.

Surface soil aggregation (cloddiness), vegetative cover, shape of the soil surface, field width, wind velocity, and surface soil moisture are primary factors influencing soil blowing. To control wind erosion it is necessary to reduce wind velocity to a nonerosive rate and/or establish protective conditions on the soil surface.

Conservationists presently use a wind erosion equation (*6*) to design wind erosion control systems and to estimate annual rates of soil loss by wind. Originally, Woodruff and Siddoway grouped eleven variables and expressed the equation symbolically:

$$E = f(I\ K\ C\ L\ V) \qquad [1]$$

where E is the potential average annual soil loss, I is a soil erodibility index, K is a soil ridge roughness factor, C is a climatic factor, L is field length along the prevailing wind erosion direction, and V is equivalent quantity of vegetative cover. Later, Skidmore and Woodruff (*4*) modified the determination of L to consider preponderance of wind erosion forces in the prevailing wind erosion direction.

The time frame for the equation is yearly, based on long-term climatic conditions. Solutions of the equation for periods of less than 1 year are not available now.

In estimating water erosion with the universal soil loss equation (USLE), the vegetative and management factor values are correlated with the rainfall erosion potential (rainfall energy) by crop-stage periods (*5*). Our purpose is to propose a means of computing wind erosion by periods (greater or smaller than 1 year) using wind-energy distributions that closely parallel the procedure used in computing the cropping and management factors in the USLE.

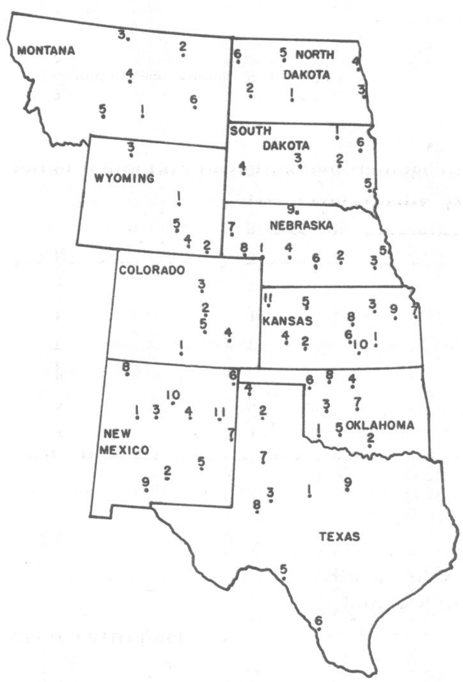

Figure 1. Key map of Great Plains for location of applicable erosive wind-energy distribution data from table 1.

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Wind energy considerations

Because no experimental field data of wind erosion rates are available for periods less than a year, a method is needed to characterize long-term erosion potential over a year based on an area's wind climatology. Erosion rates are commonly related to the cube of windspeed, $\bar{u}_z^3$ or $(\bar{u}_z - \bar{u}_t)^3$, where $\bar{u}_z$ is mean windspeed at height z above some reference plane and $\bar{u}_t$ is the threshold windspeed, the minimum needed to initiate erosion (*2*). The cube of windspeed characterizes its energy and represents a logical choice for determining distributions of wind energy over time.

We described monthly windspeed distributions by the two-parameter, Weibull distribution function (*1*) using windspeed frequency summaries (*3*) for various Great Plains locations (Figure 1). We omitted locations with less than 5 years of wind data. We determined average monthly wind energy for an interval of 8 to 20 meters per second (18-45 mph) at increments of 1 meter per second (2 mph) using the Weibull parameters (Table 1). Choice of the lower windspeed depends on threshold conditions—size and density of loose soil particles; kind, amount, and orientation of nonerodible elements; and, of course, windspeed (energy) all determine whether winds are erosive or nonerosive. We chose the upper limit because the percentage of wind energy in winds above 20 meters per second (45 mph) was insignificant at several "windy" sites in the Great Plains.

Assuming the mean windspeed profile is logarithmic with height and that soil surfaces are highly erodible sometime (i.e., loose, dry, pulverized, smooth, lacking vegetative cover, etc.), the threshold windspeed ($\bar{u}_t$) at a height of 6 to 8 meters (20-26 ft) is about 8 meters per second (18 mph). Consequently, we omitted all winds less than this in determining average cumulative wind energies (Table 1).

Two locations (Lubbock, Texas, and Valentine, Nebraska) with contrasting wind energy distribution are shown in figure 2 as a graphical example of the data in table 1.

A question arises concerning the effect of windspeed interval on energy distributions when expressed as a percentage of annual wind energy. It seems reasonable that actual wind erosion would be better related to erosive winds than to all winds, including the erosive winds. However if energies of all winds and erosive winds have similar distributions, then cululative wind energy for a given location would be the same (ex-

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Table 1. Percentage of the average annual erosive wind energy that normally occurs by the indicated dates, computed for the Great Plains locations shown in figure 1.

Location and Number	*Cumulative Erosive Wind Energy (%)* Feb. 1	March 1	April 1	May 1	June 1	July 1	Aug. 1	Sept. 1	Oct. 1	Nov. 1	Dec. 1	Jan. 1
Colorado												
1 (Alamosa)	5.1	11.8	26.7	47.0	63.7	75.8	79.9	82.9	87.3	92.4	96.2	100
2 (Colorado Springs)	7.6	17.4	32.9	49.2	63.0	73.6	77.3	79.8	84.1	88.1	94.7	100
3 (Denver)	7.2	17.3	32.4	48.2	57.7	66.4	71.3	75.4	79.4	83.3	90.6	100
4 (La Junta)	6.8	15.6	32.7	48.5	61.0	71.9	76.5	79.9	83.4	86.8	93.8	100
5 (Pueblo)	6.5	14.2	27.6	46.6	60.1	68.8	75.1	79.6	83.7	87.7	93.4	100
Kansas												
1 (Cassoday)	9.2	20.5	35.5	50.5	59.0	65.9	68.4	71.4	77.6	83.8	93.0	100
2 (Dodge City)	6.6	15.8	27.6	40.3	49.9	60.0	65.5	70.3	77.3	84.4	92.7	100
3 (Ft. Riley)	5.7	12.2	26.5	42.4	52.8	60.2	64.1	69.5	78.5	87.3	94.5	100
4 (Garden City)	5.3	13.7	25.9	38.8	50.3	64.2	70.9	77.2	84.8	90.4	95.8	100
5 (Hill City)	4.9	14.0	31.2	45.0	55.0	66.2	71.8	75.8	82.5	88.7	95.6	100
6 (Hutchinson)	7.9	18.0	29.5	41.5	51.2	61.8	66.1	69.0	77.4	85.0	93.6	100
7 (Olathe)	9.2	20.1	40.2	56.1	66.1	71.8	72.6	74.0	77.6	81.5	91.8	100
8 (Salina)	7.3	17.1	31.8	45.6	55.9	63.4	66.8	71.3	79.3	86.2	94.5	100
9 (Topeka)	7.8	17.9	35.1	52.3	61.9	69.5	72.3	75.8	80.4	85.3	94.0	100
10 (Wichita)	8.6	17.7	31.7	45.2	54.8	64.0	68.1	71.6	77.9	84.5	92.1	100
11 (Goodland)	7.0	16.4	27.4	44.2	54.1	62.2	66.0	70.8	78.2	86.3	92.8	100
Montana												
1 (Billings)	13.9	25.7	35.1	45.5	52.7	57.6	60.4	62.8	67.1	73.6	86.0	100
2 (Glasgow)	8.1	16.0	23.5	36.6	52.1	59.9	64.8	70.1	79.2	86.3	92.5	100
3 (Havre)	12.2	19.4	32.5	43.6	52.1	60.0	63.5	67.0	71.8	80.3	90.8	100
4 (Lewistown)	13.4	26.4	34.8	44.0	51.1	56.3	59.1	62.8	69.6	76.8	89.5	100
5 (Livingston)	11.4	24.0	34.2	41.7	47.4	51.1	54.6	58.6	64.1	73.1	85.5	100
6 (Miles City)	10.6	20.4	29.0	43.2	54.0	61.3	66.1	72.5	80.0	87.0	91.5	100
Nebraska												
1 (Big Springs)	7.4	15.6	28.9	43.1	53.8	61.2	66.5	71.8	77.3	84.6	93.3	100
2 (Grand Island)	6.2	13.4	26.5	42.2	53.5	62.0	66.6	70.6	76.4	82.7	92.7	100
3 (Lincoln)	8.8	18.0	35.5	52.3	63.2	69.3	72.0	74.7	78.1	83.5	93.2	100
4 (North Platte)	6.6	15.0	30.2	48.6	61.7	65.4	67.7	70.0	77.2	86.3	94.7	100
5 (Omaha)	9.0	18.2	35.5	53.2	63.7	69.6	72.6	74.9	78.3	84.5	92.4	100
6 (Overton)	7.7	14.7	28.7	46.0	56.9	66.2	68.7	71.0	73.6	80.9	93.4	100
7 (Scottsbluff)	5.8	16.4	31.0	44.4	52.6	60.2	63.5	66.8	70.0	76.7	89.9	100
8 (Sidney)	9.1	17.8	31.5	46.8	57.5	64.9	70.9	73.2	78.8	86.2	94.3	100
9 (Valentine)	4.2	11.2	20.5	33.7	43.6	51.5	55.9	62.5	69.2	78.5	92.2	100
New Mexico												
1 (Acomita)	6.2	13.7	44.8	66.7	73.2	78.9	81.7	83.8	85.5	89.1	94.8	100
2 (Alamogordo)	5.7	14.3	31.6	50.8	64.6	75.7	81.4	84.9	88.1	91.3	96.0	100
3 (Albuquerque)	4.8	13.1	27.7	46.1	61.1	72.1	78.3	80.5	85.4	91.3	96.3	100
4 (Anton Chico)	13.2	28.8	47.4	62.4	68.9	75.7	78.0	79.4	81.5	85.3	92.9	100
5 (Roswell)	7.7	17.2	30.5	43.2	54.1	65.8	72.0	76.3	80.0	85.3	92.5	100
6 (Clayton)	11.3	20.7	33.7	41.5	52.3	61.7	66.4	70.4	76.0	82.4	90.7	100
7 (Clovis)	7.5	17.7	34.5	49.5	60.8	70.4	74.7	77.3	80.7	85.1	92.0	100
8 (Farmington)	2.6	8.2	29.0	53.0	65.2	76.1	81.6	84.2	86.2	90.0	98.9	100
9 (Las Cruces)	11.8	23.4	43.7	59.6	69.5	74.5	76.5	77.8	79.1	81.0	89.5	100
10 (Santa Fe)	9.3	17.5	31.6	46.8	58.8	68.6	72.9	75.5	79.4	84.7	92.0	100
11 (Tucumcari)	10.4	23.0	37.2	51.8	63.3	71.2	73.8	76.1	78.7	85.8	92.9	100
North Dakota												
1 (Bismarck)	6.9	13.3	23.0	37.6	49.4	57.9	62.3	67.0	74.8	83.3	93.1	100
2 (Dickinson)	9.7	18.3	29.4	40.8	49.8	59.3	64.4	68.5	75.2	82.6	92.5	100
3 (Fargo)	9.2	17.8	27.7	41.8	51.2	57.4	60.6	64.4	71.0	80.2	91.2	100
4 (Grand Forks)	10.6	23.2	34.4	47.3	57.7	62.3	64.4	67.4	73.2	81.0	89.3	100
5 (Minot)	11.6	22.0	31.4	43.0	53.5	58.7	62.3	66.0	72.0	80.5	89.2	100
6 (Williston)	5.8	12.0	21.9	38.9	54.3	62.8	66.9	72.1	81.0	89.2	95.1	100
Oklahoma												
1 (Altus)	7.2	18.4	36.9	53.2	64.2	72.7	75.4	77.5	81.4	87.8	93.8	100
2 (Ardmore)	10.1	23.1	41.5	59.3	66.4	72.2	73.9	75.9	79.1	84.0	93.2	100
3 (Clinton)	9.9	21.0	39.0	55.4	68.0	74.8	76.4	77.7	81.3	85.3	91.7	100
4 (Enid)	11.2	22.8	39.7	53.0	61.1	68.4	71.4	73.9	78.2	83.4	91.3	100
5 (Ft. Sill)	8.8	20.0	34.6	47.4	56.7	65.1	68.4	71.3	76.6	83.2	91.6	100
6 (Gage)	8.6	17.0	28.3	42.0	52.6	64.9	70.2	74.2	80.6	86.5	92.9	100
7 (Oklahoma City)	8.4	17.3	30.0	44.0	54.5	65.0	69.0	72.4	77.7	84.8	92.2	100
8 (Waynoka)	7.1	17.4	31.8	45.8	56.0	63.2	69.8	72.8	79.0	86.5	94.0	100
South Dakota												
1 (Aberdeen)	7.8	15.2	27.4	42.6	52.4	60.1	64.4	69.1	76.4	84.7	93.6	100
2 (Huron)	7.5	14.9	25.7	39.6	49.4	56.2	61.0	65.8	72.6	81.0	92.3	100
3 (Pierre)	10.2	18.9	31.1	45.3	54.5	59.8	63.5	67.7	73.3	80.1	90.3	100
4 (Rapid City)	8.7	17.2	28.1	40.2	48.5	54.6	59.6	64.8	71.4	79.3	90.4	100
5 (Sioux Falls)	8.4	16.4	28.8	46.0	57.0	62.5	65.5	68.3	73.5	80.8	92.9	100
6 (Watertown)	7.8	15.2	27.4	42.6	52.4	60.1	64.4	69.1	76.4	84.7	93.6	100
Texas												
1 (Abilene)	8.3	18.2	35.7	53.1	65.1	72.3	74.2	75.7	78.9	83.6	91.9	100
2 (Amarillo)	7.7	18.3	33.0	46.4	57.8	66.2	70.7	73.5	78.7	85.0	92.5	100
3 (Big Spring)	7.6	18.0	33.8	49.7	62.0	73.4	77.5	79.8	83.1	88.1	93.9	100
4 (Dalhart)	8.1	16.3	28.0	39.6	51.1	65.9	73.4	79.1	85.1	89.5	94.2	100
5 (Del Rio)	7.4	21.0	35.3	51.4	65.5	76.1	81.3	83.8	86.8	90.0	94.4	100
6 (Laredo)	3.6	9.9	18.0	31.1	45.5	61.0	75.2	84.9	90.2	93.7	97.0	100
7 (Lubbock)	8.0	20.3	37.2	52.9	64.6	74.9	77.3	78.4	80.9	84.4	90.9	100
8 (Midland)	6.5	19.1	34.1	49.5	60.2	68.7	73.8	76.5	80.7	86.2	92.1	100
9 (Mineral Wells)	8.2	18.6	36.4	52.6	64.5	73.9	77.6	79.6	82.3	86.4	93.2	100
Wyoming												
1 (Casper)	14.8	27.8	39.3	46.6	51.6	57.1	60.1	63.2	68.4	73.8	84.8	100
2 (Cheyenne)	13.5	27.8	40.5	52.1	58.5	62.2	64.2	66.4	69.5	74.4	86.1	100
3 (Cody)	7.6	17.9	27.6	39.9	48.6	54.8	59.8	66.1	72.8	80.8	90.5	100
4 (Laramie)	13.8	27.9	42.7	51.6	59.6	66.8	68.2	70.0	74.7	80.7	89.6	100
5 (Medicine Bow)	13.7	25.8	39.8	48.8	54.3	59.2	63.1	66.4	71.6	78.3	87.5	100

pressed as a percentage). Figure 3 indicates that the stronger winds occur more frequently in the first 5 or 6 months of the year at Lubbock, Texas, while figure 4 shows only slight differences in wind distribution between all winds (1-20 meters/second) and erosive winds (8-20 meters/second) at Dodge City, Kansas. From February through May, an erosion-susceptible period, 3.0 percent more of the wind energy occurs during that period at Dodge City on the basis of erosive winds compared with all winds. The corresponding value for Lubbock is 8.1 percent. Two other locations—Valentine, Nebraska, and Midland, Texas—have values of 2.4 and 10.1 percent, respectively.

Although differences may not be great and are contingent on location, the use of energy distribution of erosive winds seems to be more sound than use of all winds to characterize erosion potential. We chose that approach in developing table 1.

Procedures and examples

Currently, in evaluating potential erosion or designing control systems using equation 1, a single value is selected for each factor I, K, C, L, and V for the entire year. The values chosen are for the "critical" month or period of the year; except for C, which is an annual value. That procedure is used because most erosion normally occurs during the critical period, and control practices are needed to provide adequate protection during that period.

Because cropping and management vary from place to place, along with the erosion hazard over the year, a procedure more descriptive of actual conditions should give more realistic answers. Our proposed new procedure allows I, K, L, and V to be determined for each crop-stage period (or other periods in question). The soil loss E obtained using period values is multiplied by the percentage of annual erosive wind energy for that period (obtained from table 1) to provide an estimate of period erosion. Adding the period amounts for the total crop sequence and dividing by the years in the sequence gives the potential average annual soil loss.

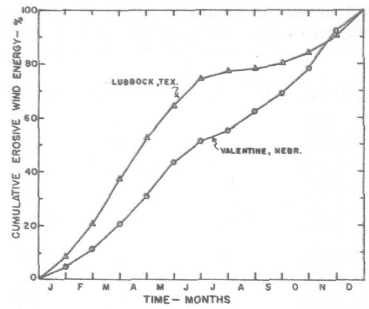

Figure 2. Average annual erosive wind-energy distribution at Lubbock, Texas, and Valentine, Nebraska.

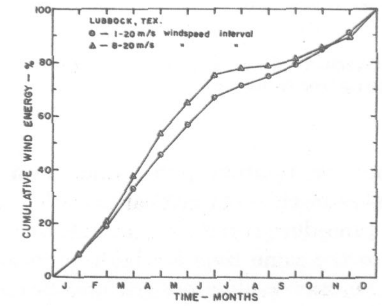

Figure 3. Average annual wind-energy distribution at Lubbock, Texas, as influenced by choice of windspeed interval.

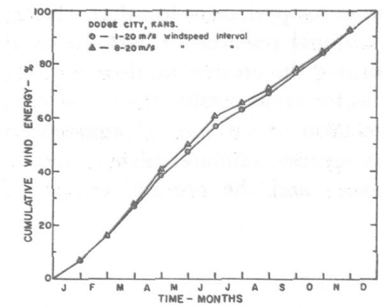

Figure 4. Average annual wind-energy distribution at Dodge City, Kansas, as influenced by choice of windspeed interval.

We selected a 2-year sequence of winter wheat-fallow near Garden City, Kansas (Figure 1, location 4), to illustrate the procedure (Table 2). The crop-stage periods are the same as those used in computing crop management factors for water erosion. Average annual erosion was about the same between the proposed procedure [5.8 metric tons per hectare per year (2.58 t/a)] and the procedure now commonly used [5.9 metric tons per hectare per year (2.63 t/a)]. However, that equality is coincidental, depending on choice of the critical period. February or March has been considered the critical month, both of which fall into the November 15 to April 15 period (during the wheat cycle). If the September 1 to October 15 period were chosen as critical, annual average E, using current procedures would be 14.6 metric tons per hectare per year (6.5 t/a/yr), considerably more than the 5.8 value determined with the new procedure.

We question whether the period chosen as critical in the past is correct. Is the period in the wheat cycle from September 1 to October 15 the critical period as suggested by the data in table 2? Historically, that has not been the observed case. Neither is it supported by duststorm data (1949-1970) at Dodge City, Kansas. Two of the equation factors (V and I) may explain the larger E values for that period. The estimated small-grain equivalent $(SG)_e$ may be too low and the selected I factor too high for this period, both of which lead to higher estimates of E.

A second example for a typical 3-year sequence of spring wheat-spring wheat-fallow near Minot, North Dakota (Figure 1,

Table 2. Example solution of wind erosion equation 1 using crop-stage periods and erosive wind-energy for a winter wheat-fallow rotation at Garden City, Kansas, I = 108 metric tons per hectare per year (48 t/a/yr), C = 100, L = 1,829 meters (6,000 ft).

Crop	Period (Month/day)	K	$(SG)_e$* [kg/ha	(lb/a)]	E [MT/ha/yr	(t/a/yr)]	EWE†	E × EWE [MT/ha/period	(t/a/period)]	E‡ [MT/ha/yr	(t/a/yr)]
Fallow	7/1 - 5/1	1.00	3,360 +	(3,000 +)	0	(0)	0.74	0	(0)	0	(0)
	5/1 - 6/1	1.00	2,800	(2,500)	0	(0)	0.12	0	(0)		
	6/1 - 7/1	1.00	2,240	(2,000)	1.6	(0.7)	0.14	0.2	(0.1)		
	7/1 - 8/1	1.00	1,680	(1,500)	8.0	(3.6)	0.07	0.6	(0.3)		
	8/1 - 9/1	1.00	1,120	(1,000)	29.5	(13.2)	0.06	1.8	(0.8)		
Winter wheat	9/1 - 10/15	0.50	560	(500)	29.2	(13.0)	0.11	3.2	(1.4)		
	10/15 - 11/15	0.50	840	(750)	18.6	(8.3)	0.06	1.1	(0.5)		
	11/15 - 4/15	0.75	1,400	(1,250)	11.8	(5.2)	0.39	4.6	(2.0)	11.8	(5.2)
	4/15 - 7/1	0.75	2,800	(2,500)	0	(0)	0.31	0	(0)		
Total							2.00	11.5	(5.1)	11.8	(5.2)
Average								5.8	(2.6)	5.9	(2.6)

*Flat small grain residue equivalent.
†Erosive wind-energy; proportion during period.
‡Potential average annual erosion using current procedure of selecting a "critical" period as the basis for determining E.

Table 3. Example solution of wind erosion equation 1 using crop-stage periods and erosive wind-energy for a spring wheat-spring wheat-fallow rotation at Minot, North Dakota, I = 108 metric tons per hectare per year (48 t/a/yr), C = 20, L = 1,829 meters (6,000 ft).

Crop	Period (Month/day)	K	$(SG)_e$* [kg/ha	(lb/a)]	E [MT/ha/yr	(t/a/yr)]	EWE†	E × EWE [MT/ha/period	(t/a/period)]	E‡ [MT/ha/yr	(t/a/yr)]
Fallow	8/15 - 5/15	0.75	2,915	(2,600)	0	(0)	0.84	0	(0)	0	(0)
	5/15 - 9/1	1.00	1,570	(1,400)	0	(0)	0.18	0	(0)		
	9/1 - 3/15	1.00	225	(200)	7.9§	(3.5)	0.61	4.8	(2.1)		
	3/15 - 4/25	1.00	225	(200)	17.2	(7.7)	0.14	2.4	(1.1)	17.2	(7.7)
Spring wheat	4/25 - 5/10	0.75	225	(200)	13.7	(6.1)	0.05	0.7	(0.3)		
	5/10 - 5/20	0.75	450	(400)	10.1	(4.5)	0.03	0.3	(0.1)		
	5/20 - 6/5	0.75	1,120	(1,000)	2.3	(1.0)	0.05	0.1	(0.1)		
	6/5 - 8/15	0.75	2,915	(2,600)	0	(0)	0.10	0	(0)		
	8/15 - 9/1	0.75	2,915	(2,600)	0	(0)	0.02	0	(0)		
	9/1 - 3/15	1.00	225	(200)	7.9§	(3.5)	0.61	4.8	(2.1)		
	3/15 - 4/25	1.00	225	(200)	17.2	(7.7)	0.14	2.4	(1.1)	17.2	(7.7)
Spring wheat	4/25 - 5/10	0.75	225	(200)	13.7	(6.1)	0.05	0.7	(0.3)		
	5/10 -5/20	0.75	450	(400)	10.1	(4.5)	0.03	0.3	(0.1)		
	5/20 - 6/5	0.75	1,120	(1,000)	2.3	(1.0)	0.05	0.1	(0.1)		
	6/5 - 8/15	0.75	2,915	(2,600)	0	(0)	0.10	0	(0)		
Total							3.00	16.6	(7.4)	34.4	(15.4)
Average								5.5	(2.5)	11.5	(5.1)

*Flat small grain residue equivalent.
†Erosive wind-energy; proportion during period.
‡Potential average annual erosion using current procedure of selecting a "critical" period as the basis for determining E.
§Soil erodibility (I) assumed to be reduced 50 percent after plowing.

location 5), indicates average annual erosion of 11.5 metric tons per hectare per year (5.1 t/a/yr) compared with 5.5 metric tons per hectare per year (2.5 t/a/yr) for the new procedure (Table 3). In this case, the choice of critical period coincides with the largest erosion rate computed from equation 1. One change from the previous example was recognition that plowing usually increases nonerodible surface-soil aggregates, which permits a lower I-factor to be used during the period immediately after plowing (September 1-March 15 during the wheat cycle).

Although the two examples cover 2- or 3-year crop rotations, the new procedure could be used to estimate erosion amounts for shorter periods of interest, for example, immediately after plant emergence (May 10-May 20 in table 3). The predicted erosion of 0.3 metric tons per hectare could be used as the basis for determining control practices for reducing or eliminating abrasive damage to young seedlings from blowing soil. The new procedure's capability on this count might be more important for abrasion-sensitive crops, such as sugar beets or high-value horticultural crops.

Conclusions

Computations distributing potential wind erosion amounts over time according to erosive wind-energy distribution have several advantages over present procedures. We are confident that factors in the wind erosion equation, especially I, V, and K, change over the year or crop sequence, and those changes should be considered in estimating potential erosion amounts. The new procedure allows use of different equation factors for different periods. We can analyze weak points in the crop sequence or rotation and avoid possible mistakes in choosing critical periods. The new procedure correlates amounts of residue to the same time for both wind and water erosion evaluations and may be used to determine when the most erosive or hazardous period occurs.

On the negative side, the new procedure requires more man-hours to work out necessary solutions. Also, no experimental data base exists for using the wind erosion equation for periods of less than 1 year.

Additional research or data are needed concerning the erosive wind-energy distributions for areas outside the Great Plains; the relation of surface soil aggregates to soil properties, climate, tillage, and crop sequence; and the erosion amounts for shorter periods, such as single months or single windstorms.

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