Climatic Factor for Estimating Wind Erodibility of Farm Fields

BY W. S. CHEPIL, F. H. SIDDOWAY, AND DEAN V. ARMBRUST

Recently developed wind erosion climatic factor permits rapid determination of average annual soil loss due to wind erosion on any given field.

THIS STUDY is a continuation of a research project to evaluate major soil and surface conditions that influence wind erodibility of farm fields. To some degree, seven types of conditions have been evaluated: Soil cloddiness, clod stability against abrasion from wind erosion, vegetative residues above the ground surface, surface roughness, wind barriers, width of field, and wind direction in relation to field orientation (*7*, *8*, *9*). All have been evaluated for climatic conditions existing in the vicinity of Garden City, Kansas, for the period 1954-1956. Alignment charts and tables prepared as a result of these studies can be used to indicate approximately the wind erodibility of any farm field under the climatic conditions considered.

The charts and tables can also be used in reverse to determine the field conditions needed to reduce the field erodibility to an insignificant quantity under these particular climatic conditions. But the field conditions required in one region are expected to be different from those required in another, because the general level of wind velocity, the quantity and frequency of rainfall, and the rate of drying of the soil surface differ from one region to another. The problem has been to determine how much the wind velocity-surface soil moisture factor, hereafter called the wind erosion climatic factor, of the different regions directly influences the average rate of wind erosion; and conversely, to what degree controllable field conditions must be modified in different regions to reduce wind erosion to an insignificant quantity. This article presents the results of a study of this problem.

The wind erosion climatic factor considered in this paper, like all conditions associated with wind erosion, directly influences the amount of wind erosion of farm fields. It is true that soil moisture influences soil cloddiness and crop residues, which in turn influence wind erosion, but this is not the moisture evaluated in this paper. The moisture evaluated is that adhering to the soil particles subjected to the force of erosive wind. It is known that as soil particles become more moist, the cohesive force between the particles increases; therefore, a higher wind velocity is required to move them (*6*). By the same token, the more frequently the soil surface is wetted and the more slowly it dries, as in humid regions, the less the soil will be subject to wind erosion. The wind erosion climatic factor is used here merely as an index of the influence the average moisture content in the surface soil particles and the average level of wind velocity have on the average rate of soil movement by wind.

Method of Evaluation

The rate of soil movement varies directly as the cube of wind velocity (*1*, *5*, *16*) and inversely as approximately the square of effective moisture W, i.e., moisture held by the soil particles against a given tension exerted by forces of evaporation acting on the soil particles (*6*). The effective moisture varies directly with the amount of precipitation and inversely as the square of temperature (*2*).

Wind velocity data for different regions are available from weather records, but information on the moisture of the soil surface is not. However, the Thornthwaite moisture index (*15*) and the P-E index (*14*) are available; either

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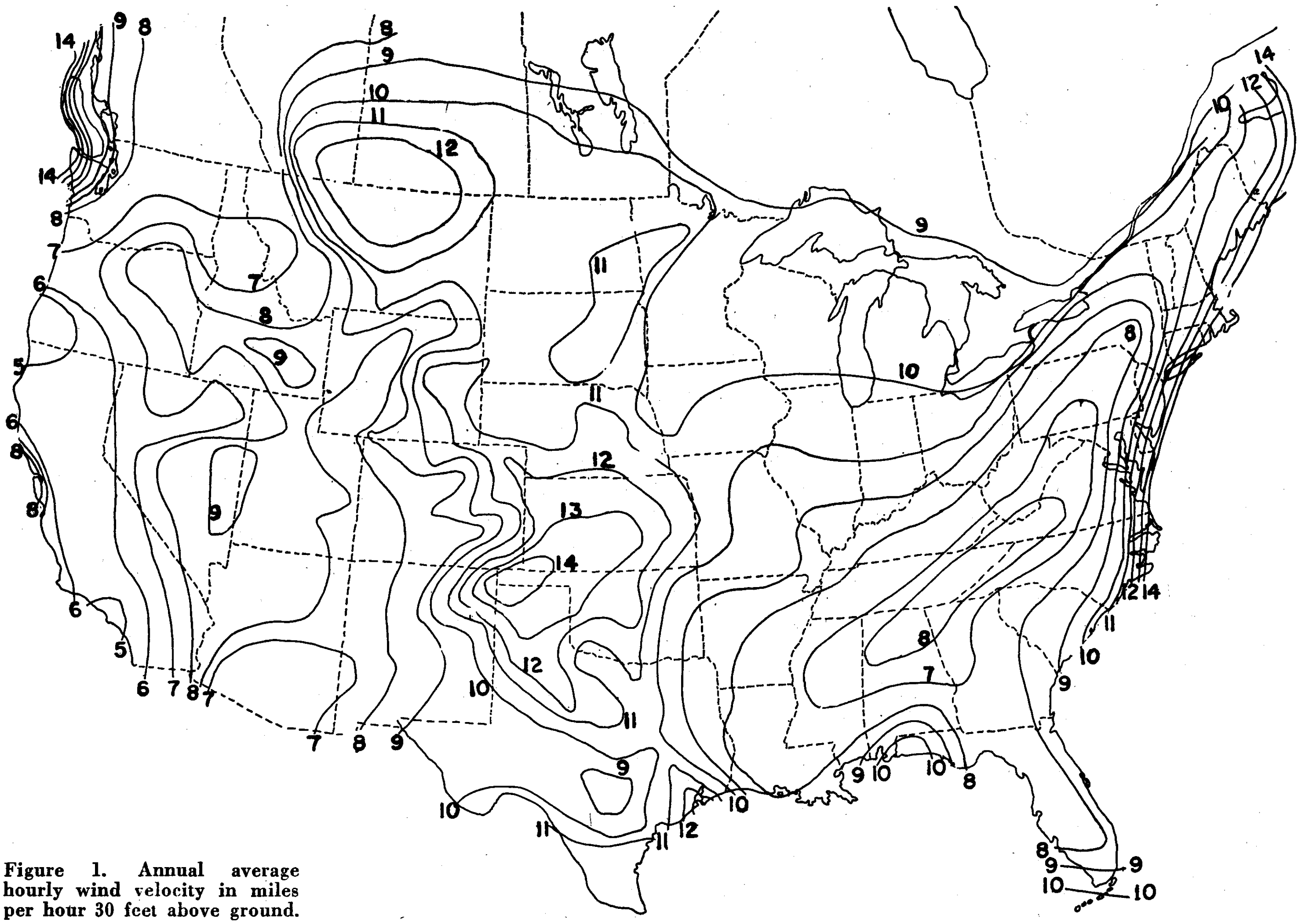

Figure 1. Annual average hourly wind velocity in miles per hour 30 feet above ground.

one can be used as an index of the quantity of equivalent moisture of the surface soil particles. If it is assumed that the effective moisture of the surface soil particles varies as the moisture index *I* or as the *P-E* index, then the combined wind erosion climatic factor *C* may be expressed in percent of that at Garden City, Kansas, as

(equation 1)

$$C = 100\frac{V^3}{(I+60)^2}/1.9$$

(equation 2)

$$\text{or } C = 100\frac{V^3}{(P\text{-}E)^2}/2.9$$

In this equation, *V* is the corrected mean annual wind velocity for a standard height of 30 feet, 1.9 is the approximate average value of $V^3/(I+60)^2$ for Garden City, Kansas, and 2.9 is the approximate average value of $V^3/(P\text{-}E)^2$ for Garden City, Kansas; at this location $V = 13.5$ miles per hour, $I = -24$, and $P\text{-}E = 29$. The purpose of adding 60 to the moisture index *I* is to express all values of $I +$ 60 as positive numbers. This must be done to make the dimensionless equation meaningful. The values of the wind erosion climatic factor *C* are the same whether $I + 60$ or *P-E* is used, since $P\text{-}E = 0.8\ I + 48$. The wind erosion climatic factor, as expressed by equations 1 and 2, indicates the relative mean rate of wind erosion that would occur at any geographic location as a percentage of the mean rate that would occur at Garden City, Kansas, if conditions other than climate were the same.

Sources of Data

Climatological data published by the U. S. Weather Bureau and the Canada Meteorological Branch for 243 selected meteorological stations were used for this study. Temperature and precipitation records were used to compute the *P-E* index (*14*). In addition, the Thornthwaite (*15*) moisture index map of the United States was utilized. Only 145 of the 243 stations had adequate records of wind velocity, temperature, and precipitation; the remainder lacked the necessary wind velocity data. It was thought that published wind velocity maps might be used to estimate wind velocity for the rest of the selected stations, but review of meteorological publications failed to reveal the existence of maps adequate for this purpose. Therefore, a map based on data from the 145 stations for the period 1920-1958 and showing annual hourly wind velocity at a 30-foot height for southern Canada and the United States was prepared. This map, shown in figure 1, served to estimate approximate wind velocity for the 98 stations for which adequate wind velocity records were not available.

Since height at which wind velocity was measured varied considerably, the velocities shown in figure 1 were corrected to 30-foot height in accordance with the Hellman formula expressed in a convenient nomogram by Thom (*13*).

Wind velocity data taken in cities were avoided. Data from only 30 stations east of the ninety-fifth meridian

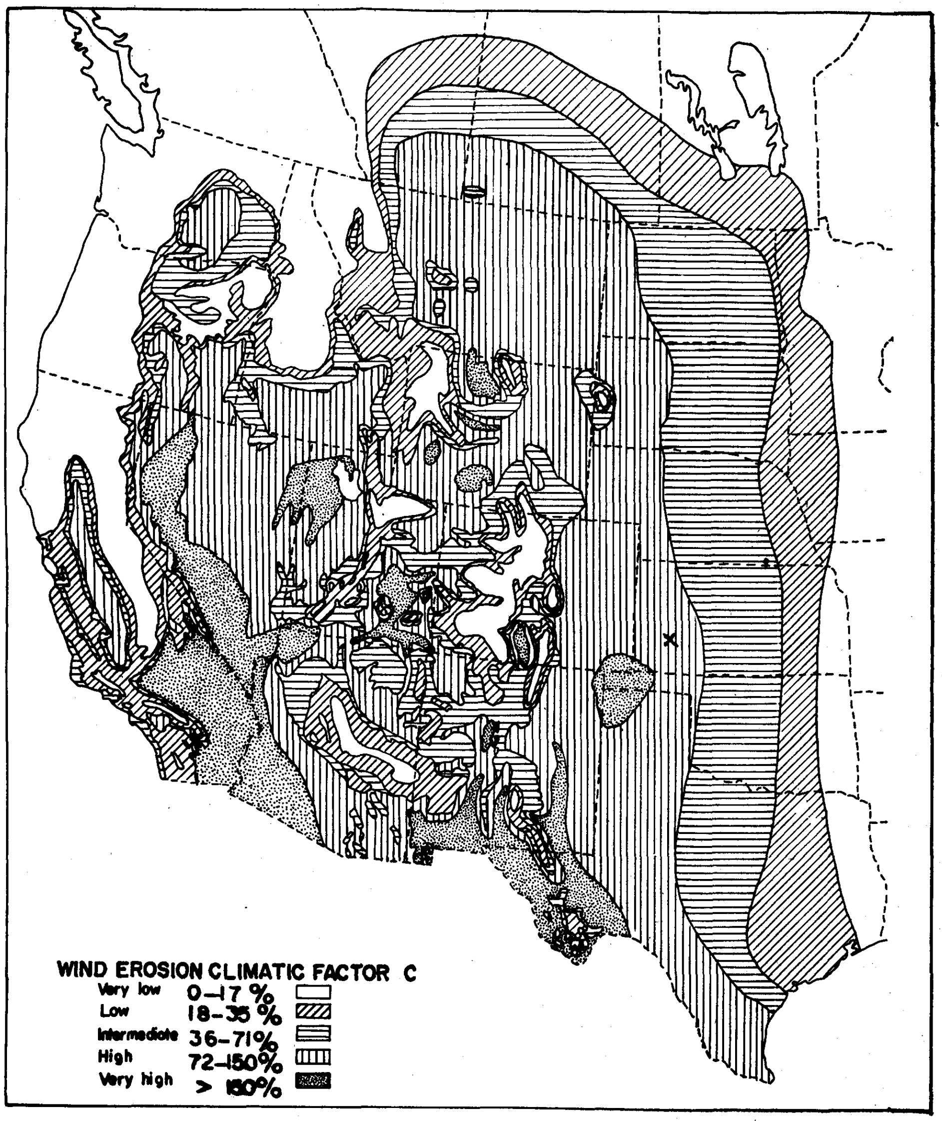

Figure 2. Wind erosion climatic factor expressing soil loss by wind in terms of percentage of that occurring in the vicinity of Garden City, Kansas (marked by X). The eastern portions of the United States and Canada not shown on the map have a very low factor, less than 18 percent.

were used. A greater number of stations was unnecessary because the computed values of the wind erosion climatic factor for this huge area were generally less than 18 percent and fell into the "very low" category, which needed to be delineated only from the next higher category occurring to the west of it.

Wind Erosion Climatic Factor Map

A map indicating the wind erosion climatic factor computed in accordance with equation 2 for the United States and southern Canada is given in figure 2. This map was prepared on the basis of wind velocity and *P-E* values for the 243 selected stations; but in addition, for estimating the wind erosion climatic factor for areas located between the stations, considerable use was made of the moisture index map of the United States prepared by Thornthwaite (*15*), the precipitation map of the United States prepared by Kincer (*11*), the natural vegetation map of the United States by Shantz and Zon (*12*), the natural vegetation map of Canada by Chapman (*4*), and the soil map of the Canadian Prairies by Bowser (*3*). Despite the use of this indirect method of delineating the wind erosion climatic factor for the different regions, many small areas could not be determined on the scale of maps used.

The wind erosion climatic factor, as shown in figure 2, is divided into five categories. With some major exceptions, the boundaries of these categories generally coincide with those of humid, moist subhumid, dry subhumid, semiarid, and dry climatic types, as classified by Thornthwaite (*14, 15*). The exceptions occur because the average wind velocity varies from region to region. One striking exception is an area in the semiarid region in the Texas and Oklahoma Panhandles and adjacent portions of other states that falls into the category of regions having a wind erosion climatic factor typical of desert areas. The average wind velocity in this area is higher than anywhere else in Canada and the United States, except for those regions along the North Atlantic seacoast, around the Gulf of St. Lawrence, and in the vicinity of Vancouver Island. This panhandle region is the heart of an area most severely affected by wind erosion in North America; it is the center of the dustbowl of the 1930's. Most of the rest of the regions falling into the "very high" wind erosion climatic factor category are uncultivated deserts.

Use and Significance of the Factor

If the potential annual soil loss estimated for a field on a particular soil class at some geographic location is multiplied by the wind erosion climatic factor *C* for that location, the value so obtained is called the local potential annual soil loss and indicates the potential loss corrected for mean differences in wind velocity and moisture of the soil surface between that location and Garden City, Kansas.

Soil losses that can be estimated from major soil, surface, and field conditions which influence wind erosion are based on climatic conditions as they existed at Garden City, Kansas, during the years 1954 through 1956, but the wind erosion climatic factor of 100 percent is based on the long-term average wind velocity and soil moisture index for that location. Since wind velocity and moisture intensities are normally distributed (*10, 17*), the value taken as 100 percent is immaterial so long as it is specifically defined.

Probably one of the best ways to define the 1954–1956 period is by percentage frequency of occurrence of climatic conditions that influenced wind erosion during those years at the Garden City, Kansas, location. This was done by plotting the 3-year running average of annual wind velocity divided by annual *P-E* index against the frequency of occurrence scale in accordance with the simplified method of Gumbel (*10*). The climatic ratios so plotted are shown in figure 3. It is evident from figure 3 that the 3-year severity of climatic conditions that influenced wind erosion (annual wind velocity divided by the annual *P-E* index) equal to or greater than that existing during the period 1954–1956 occurs at that location on the average once in about 7 years. The period 1954–1956 at Garden City had numbers and intensities of dust storms exceeded only by those of the 1930's. The severity of climatic conditions that influence wind erosion, as shown in figure 3, also was exceeded only by that of the 1930's, thereby substantiating the validity of the wind erosion climatic factor as an index of severity of wind erosion.

A wind tunnel erodibility value of 0.25 was regarded as representing an insignificant amount of soil loss (*7*). Subsequently, this was found to correspond to an annual soil loss of 15 tons per acre under the weather conditions that existed during the period 1954–1956 at Garden City, Kansas (*8*). The wind erosion climatic factor *C* for that period at Garden City was 250 percent, whereas the average for that location is 100 percent. Therefore, the average annual soil loss for insignificant erosion determined on the above-mentioned basis is $\frac{100 \text{ percent}}{250 \text{ percent}} \text{ x } 15 = 6$ tons per acre. An average annual soil loss not exceeding 5 tons per acre should probably be the goal. Like all soil loss values, this one is primarily an index of wind erosion damage and is not the damage itself. The 5-ton per acre average annual soil loss is associated with no visible soil movement and no injury to plants.

The wind erosion climatic factor for any region is used to determine the average annual soil loss on any given field in that region. Inversely, it is used to determine the field conditions necessary to prevent the average annual soil loss from that field from exceeding 5 tons per acre. If the intensity of practices required to reduce soil loss to that average insignificant amount is unattainable or if practice intensity exceeds requirements, the wind erosion climatic factor can be modified uniformly one way or another simply by raising or lowering the average amount of soil loss popularly regarded as insignificant. Currently, we believe that the average insignificant amount of soil loss should be about 5 tons per acre per year; this corresponds to an average wind tunnel erodibility of about 0.25. Annual soil loss per acre can be reduced to this amount anywhere with reasonably good and uniform wind erosion protection.

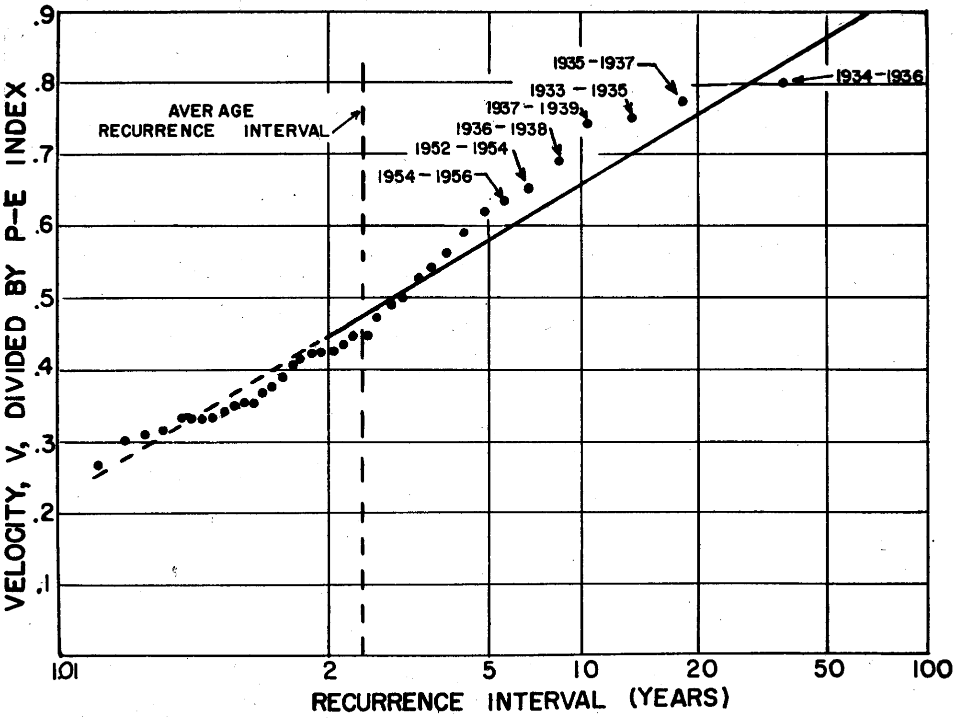

Figure 3. Intensity-frequency data for 3-year running average of wind velocity *V*, corrected to that at 30-foot height, divided by the *P-E* index at the Branch Agricultural Experiment Station, Garden City, Kansas, for 1920 through 1960.

Conclusion

The solution of this problem (shown in figure 2) pertaining to the relative climatic influence on field erodibility in different regions has been drawn from reasoning based on known relationships between wind velocity, surface soil moisture, and rate of soil movement by wind. It is known that soil movement varies directly as the cube of wind velocity and inversely as the square of effective moisture of the surface soil. If it is assumed that the *P-E* index is an index of effective moisture of the surface soil as manifested by quantity and frequency of rainfall and rate of drying of the surface soil, then it is reasonable to expect that wind erosion should vary inversely as the square of the *P-E* index. Only the future use of the wind erosion climatic factor in different regions can ultimately determine its accuracy in predicting conditions required to control wind erosion in different regions.

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