Wind Patterns and Soil Erosion[1] on the Great Plains

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Abstract.--Knowledge about wind climatology is essential in assessing the need for wind erosion protection. Great Plains wind data availability and factors (station density, anemometer height, and time base) affecting data credibility are identified. Annual wind-erosion land-damage averages 5 million acres in the Plains, and wind erosion equation calculations indicate coarse-textured soils in western Texas, western Kansas, and eastern Colorado are highly erosion-susceptible.

INTRODUCTION

"The wind blows where it wills" (Bible 1972) is a biblical statement indicating man's lack of control over wind's occurrence, speed, direction, duration, and distribution. Wind, of course, is the force behind all soil blowing in the Great Plains area, and knowledge about its characteristics is essential in assessing the need for wind erosion protection on agricultural lands.

WIND PATTERNS

Data Availability

The most recent information concerning wind data (essential for determining wind patterns in any geographical area) available at the National Climatic Center (NCC), Asheville, N.C., is contained in an excellent report by Changery (1975). That report was stimulated by the current interest in wind as an energy source. Report items of interest to participants in a "windbreak" symposium would be: (1) the observational network, (2) history of wind observations, (3) availability of hourly wind data on land, (4) summarized wind data on land, and (5) gusts and maximum wind data.

Stations in the Great Plains with wind summaries archived in the NCC for 10 years or more are given in figure 1. Notable areas lacking such data are northeastern New Mexico, Oklahoma Panhandle and western Kansas, northeastern Colorado and most of Nebraska, and areas of northeastern Wyoming, southeastern Montana, southwestern North Dakota, and northwestern South Dakota. Perhaps of more interest are the stations with hourly summaries for 5 years or more in the Plains states (fig. 2). Five years is the minimum needed to tentatively describe the wind climatology of a location.

Many of the data taken since the mid-1940's at locations operating continuously are available on punched cards and magnetic tape. Figure 3 shows areas that stations in the Great Plains cover and times (years) covered by data available. Through 1964, all elements recorded hourly, except wind gusts, are digitized. Beginning in January 1965, only every third hourly observation made at the National Weather Service and Federal Aviation Agency stations is digitized. The intermediate hourly observations can be obtained from the original reporting forms. Air Force station hourly data are digitized through December 1970. From January 1971, unedited hourly data obtained from teletype sequences are available on tape for U.S. Air Force locations.

Copies of magnetic tape or punched cards will be furnished by NCC or original observations will be special-keyed at cost.

Data Credibility

From the beginning, the National Weather Service has used vertical-axis, rotating-cup anemometers to record windspeed. Since only minor changes in anemometer design have been made through the years, such changes should not significantly affect data quality among stations.

Data extrapolation or interpolation must be used for sites that have no weather station.

1/ Paper presented at the symposium: "Shelterbelts on the Great Plains", Denver, Colorado, April 20-22, 1976.

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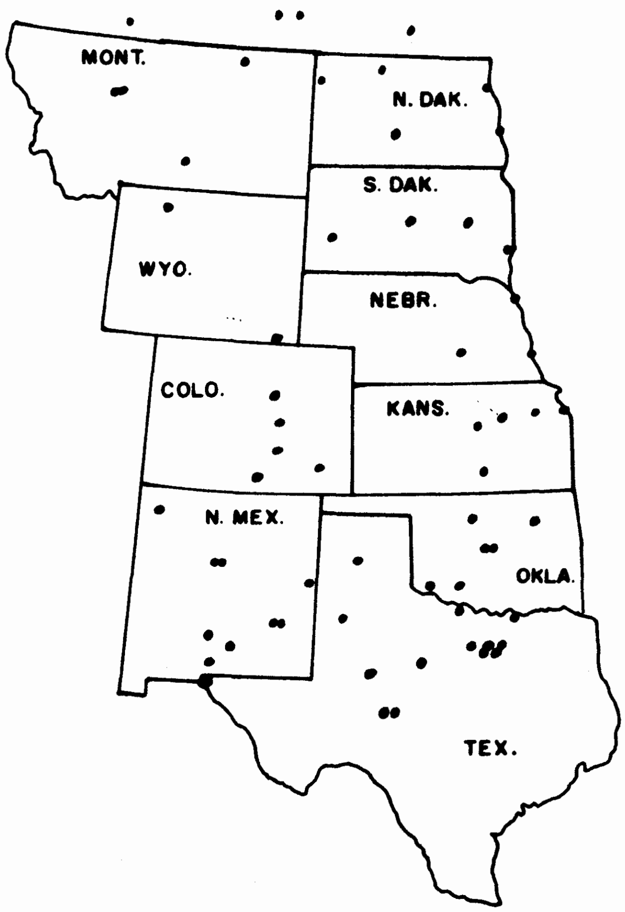

Figure 1.--Stations with wind summaries of 10 or more years' data (from Changery 1975).

Variation in station density within and among states is shown in figures 1-3. Horizontal data extrapolation or interpolation beyond 30 miles is unlikely to be more than 75 percent accurate. However, the problem associated with station density is not so severe over flat terrain, like the Great Plains, as it is over mountainous regions. Surface terrain and roughness and atmospheric thermal stratification profoundly affect the boundary-layer wind profile both horizontally and vertically.

Although an attempt is being made to standardize anemometer heights to 10 meters, many observations are made at 6 to 20 meters; in the past some may have been 60 meters or more above the surface. For example, the anemometer height at Dodge City, Kansas, changed 5 times between 1886 and 1942 (Zingg 1949). Fifteen of 20 stations studied by Johnson (1965) had different anemometer heights. Effects of elevation on wind measurements must be removed by correcting to a standard height for accurate station comparisons. Unfortunately, when anemometer height is changed, its horizontal location may also change. Perhaps it is an atypical situation, but the horizontal location of the anemometer at Dodge City, Kansas, changed 8 times between 1874 and 1942 (Zingg 1949).

Various procedures have been used or suggested to adjust windspeed to a standard height at the same station or among stations. Zingg (1949), summarizing Dodge City data, adjusted earlier data to a standard height and location at the airport on the basis of long-time averages and deviations. Johnson (1965) adjusted windspeeds for 20 stations in the southwestern Great Plains to a standard height of 35 feet from wind profile measurements (7 heights) over buffalograss sod at Bushland, Texas, in 1962. The Bushland data were plotted on semilog paper (the well-known log law that windspeed is proportional to the log of height above ground) and extrapolated up or down, depending on anemometer height and windspeed groups at a given location. That procedure assumes that changes in terrain and surface roughness at specific sites do not change the velocity-height relationship significantly. Reed (1975) suggested that reasonable "ball park" estimates of wind power may be made with the "one-seventh law" for windspeed. That law states that windspeed is proportional to the one-seventh power of height above ground.

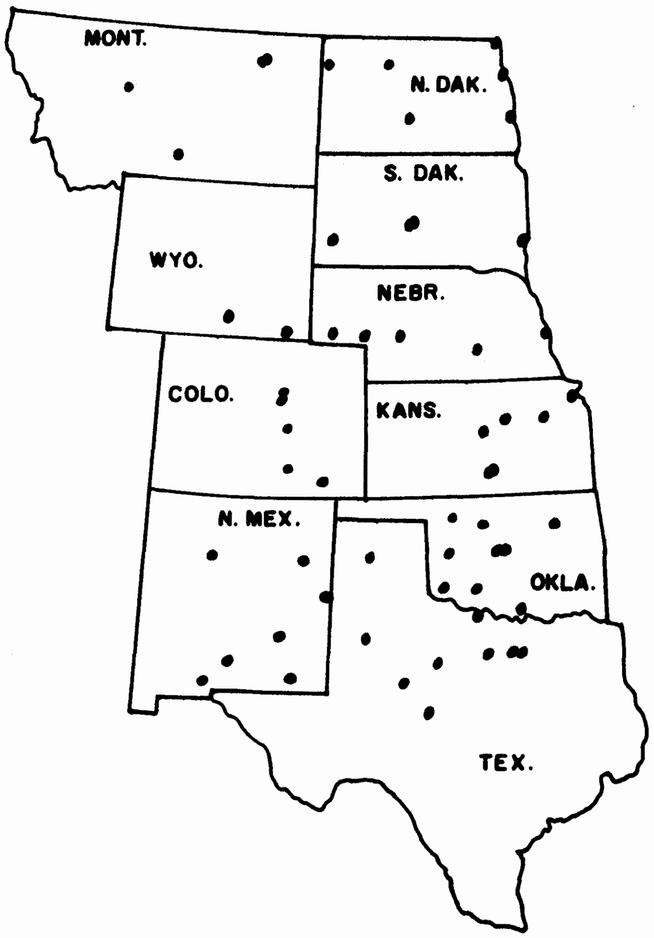

Figure 2.--Stations with hourly summaries for 5 or more years (from Changery 1975).

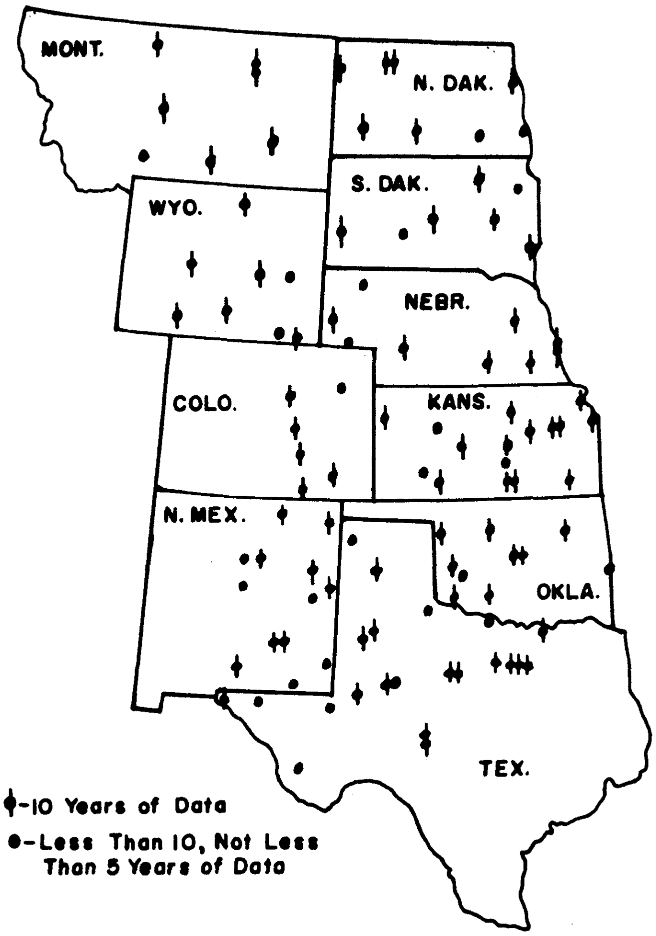

Figure 3.--Stations with data on magnetic tape (from Changery 1975).

The time base for wind data is highly important. At present, data are digitized at 3-hour intervals (at NCC). This is considered satisfactory to assess prevailing direction but not speed distributions. Hourly windspeed reporting requirements specify averaging the wind for a 1-minute interval once each hour. Studies indicate that the true average windspeed over an hour is somewhat greater than the average as now determined. If instantaneous windspeeds are cubed over an hour and averaged, the result may be considerably greater than the result from cubing the average speed. By using different time base periods among station comparisons, one may draw incorrect conclusions. Figure 4 indicates that winds are strongest during drought years and thus increase the wind-erosion potential. But more locations and years of data are needed to validate the indicated relation between drought and occurrence of strong winds.

Data Presentation

Reduction of wind data to a proper and useable form depends on user requirements. In general, interest in wind data encompasses speed and direction (in some cases) and their variations over time and space. Those interested in wind as an energy source have little concern about direction, except as it influences equipment design. Reed's (1975) data in a recent summary of wind power climatology of the U.S. do not discriminate by direction, making them less useful for agricultural purposes. Also, he did not correct for anemometer height.

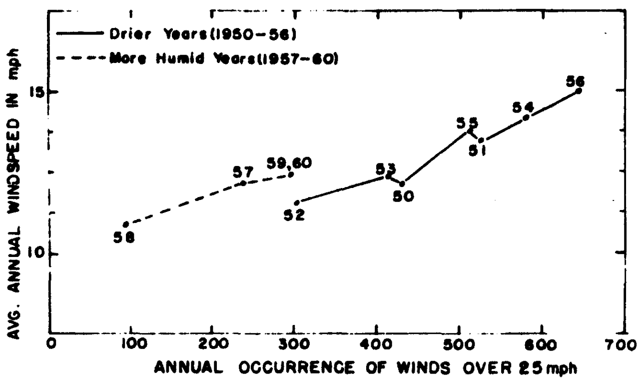

Figure 4.--Relation between number of observations of winds exceeding 25 mph and average annual windspeed at Amarillo, Texas, as influenced by drought. Data from Johnson (1965).

Johnson (1965) presented tabular data by monthly percentage frequency of occurrence according to 8 speed groups and 8 directions. The time base was 1950-54 for 11 stations and 1954-58 for 9 stations. The different time bases and short duration of data (5 years) somewhat limit conclusions from the data. Figure 5 illustrates one method of presenting wind data for the stronger winds but lacks directional information. Johnson (1965) indicated windiness by showing windspeed ranges for March that were exceeded 2 percent of the time in his study area (fig. 6).

The marked difference between the monthly average windspeed and average fastest mile for Dodge City is illustrated in figure 7. The ratio ranged from 1.72 in September to 1.92 in June. The fastest mile is the highest windspeed for 1 minute during a 24-hour period (daily). The daily values were averaged over the month; then monthly averages were averaged for the 6 years (1970-75).

The annual extreme for a 25-year recurrence interval in the Great Plains is about 70 mph, with two regions having 80 or more mph (fig. 8).

Skidmore (1965) and Skidmore and Woodruff (1968), recognizing that wind power (its potential to cause erosion) is related to the cube of its speed, presented data by months for 212 locations in 39 states in terms of (1) relative magnitude, (2) prevailing wind erosion direction, and (3) preponderance of wind erosion forces in prevailing wind erosion direction. Those factors indicate potential need for wind erosion protection, proper orientation of a suitable barrier to reduce the wind erosion forces, and relative merits of proper orientation of a barrier, respectively. They excluded winds of 12 mph or less from their analyses because such winds were considered nonerosive. The time base was between 1 and 25 years, with 5 years of data for about 30 percent of the stations. No corrections were made for height of measurement.

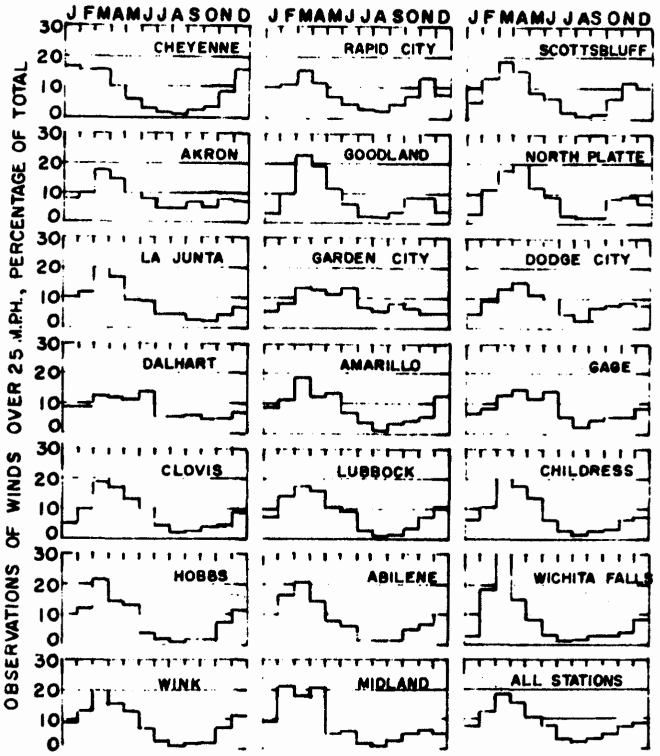

Figure 5.--Percentage of hourly wind observations of winds exceeding 25 mph by month and location (from Johnson 1965).

Figure 9, which presents some relative data for March, was computed from Reed's data (1975) or taken from Skidmore and Woodruff (1968). Why the data from the two sources differ for the same station is not known. For 17 of 22 stations, Skidmore and Woodruff's data (S-W) were larger than Reed's. Differences were large at Amarillo, Texas; Albuquerque, N.M.; Cheyenne, Wyo.; and Great Falls, Mont. At North Platte, Nebr., however, S-W data were much smaller. Several of the factors discussed under the data credibility section are probably responsible for these differences. Considering only Reed's data (1975) in figure 9, the relative value at Dickinson in southwestern North Dakota appears much too large compared with values for other stations in North Dakota and eastern Montana. Also, Gage, Okla., has stations on two sides that have relative values twice as large as its value.

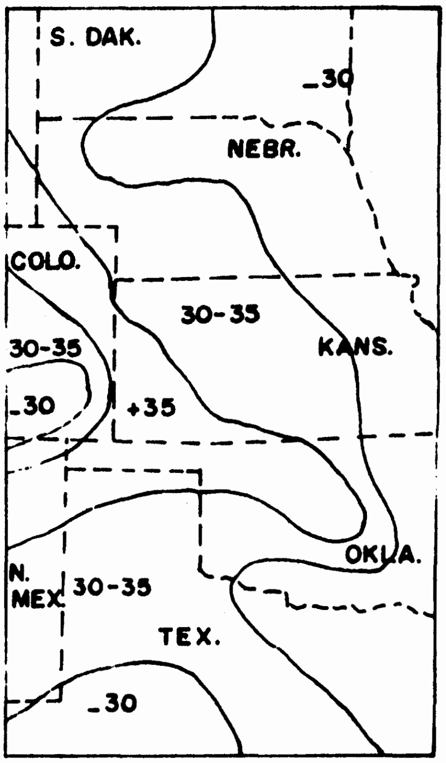

Figure 6.--Relative windiness in March. Windspeeds indicated (mph) are exceeded 2 percent of the time and are for a standard height of 35 feet (from Johnson 1965).

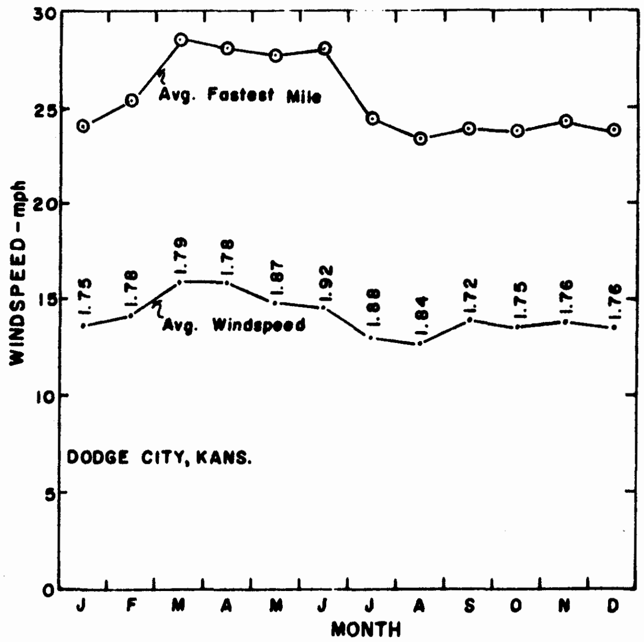

Figure 7.--Monthly average windspeed and fastest mile for Dodge City, Kansas, for 1970-75. Numbers above the average windspeed line are 6-year averages of the ratio of average fastest mile to average windspeed.

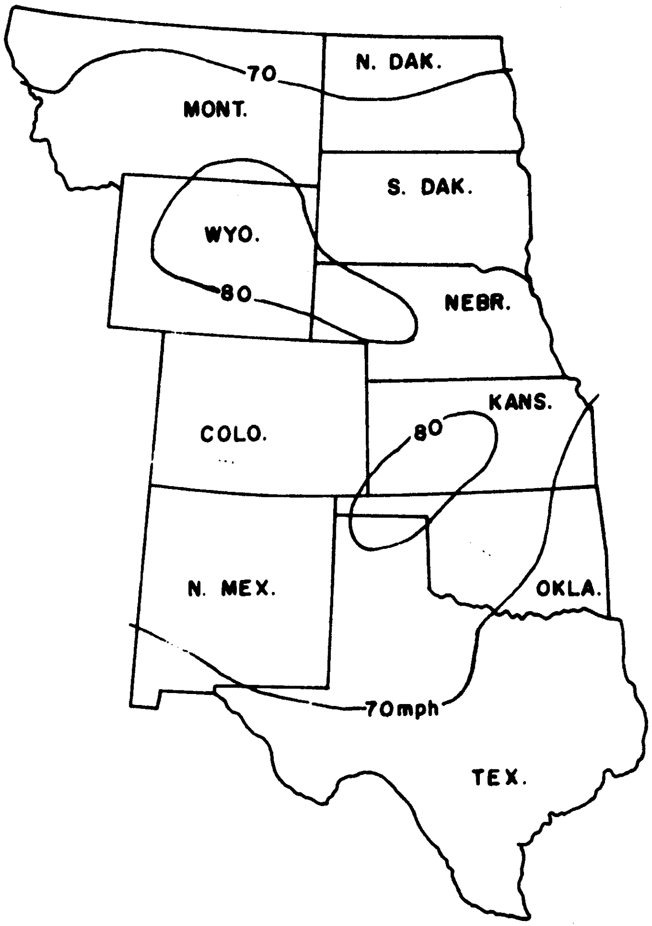

Figure 8.--Annual extreme-mile 30 feet above ground, 25-year recurrence interval (from Thom 1968).

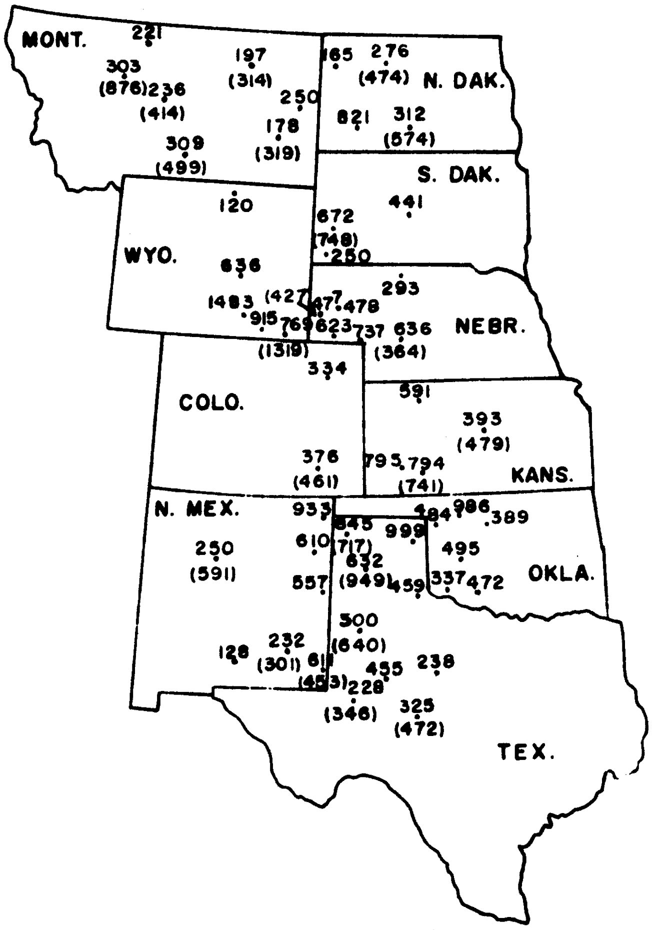

Figure 9.--Relative magnitude (sum of windspeed cubed times a duration factor for winds exceeding 12 mph) of wind in March computed from Reed's data (1975). Numbers in parentheses are from Skidmore and Woodruff (1968).

The threshold windspeed of 11 to 13 mph is for a 1-foot height. Because most anemometers at weather stations are 20 to 70 feet high, corresponding threshold windspeeds would be 19.8 to 23.0 mph for those heights, respectively, assuming a roughness parameter (Z_o) of 0.3 cm over a smooth, fallow field. However, Z_o for surface conditions near weather stations in the Plains may be an order of magnitude larger, i.e., 3 cm. Using that Z_o and methods of Simiu (1973), the threshold windspeeds would be 16.1 and 19.9 mph for heights of 20 and 70 feet, respectively. A relative factor, which excludes windspeeds below the threshold, based on actual anemometer height (not 1 foot) would seem to be an appropriate indicator of the potential for wind erosion (fig. 10). However, viewing the data creates some doubt that the computed station values truly represent the wind climatology of the surrounding area. In some instances they may reflect only terrain features near the stations. On-site inspections are needed to evaluate anemometer locations and estimate Z_o. Such variability in data among stations supports the needs for standardizing anemometer height and locating stations on sites representative of agricultural lands.

SOIL EROSION

The severity of wind erosion depends on equilibrium conditions among soil, vegetation, and climate. Erosion may be expected wherever the surface soil is fine, loose, and dry; the surface is smooth and bare; and fields are unsheltered, wide, and improperly oriented to prevailing wind direction.

Extent of Problem

Wind erosion is a severe problem on about 70 million acres of land in the United States (USDA 1965); about 55 million acres are cropland--the other 15 million acres are rangeland or other lands. A further breakdown of cropland shows 23 million acres in the Northern Plains (N. Dak., S. Dak., and Nebr.), 12 million acres in the Southern Plains (Kans., Okla., and Tex.), and 15 million acres in the Mountain States (Idaho, Utah, Nev., Ariz., Mont., Wyo., Colo., and N. Mex.).

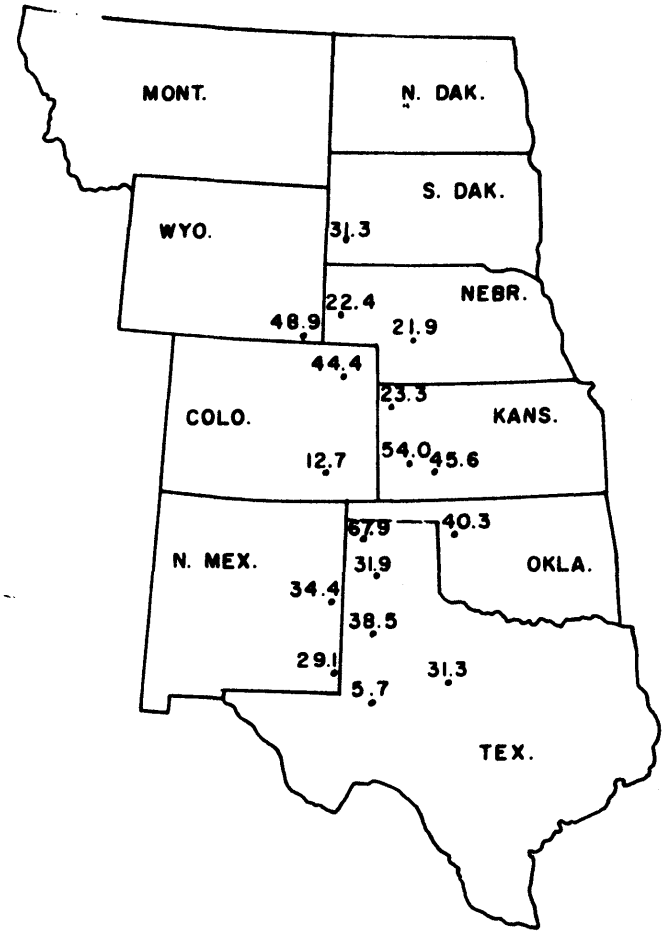

Figure 10.--Annual relative magnitude of erosive winds for selected stations computed from Johnson's (1965) basic data.

Land in the 10 Great Plains States damaged annually by wind erosion has ranged from 1 to 16 million acres, with a 40-year average of about 5 million acres[3] (fig. 11). Land damaged is described by the Soil Conservation Service as "Land where soil removal or deposition by wind erosion has been enough to subject it to further erosion hazards, materially lower yields, or impair inherent productive capacity. For cropland this means surface soil removed, surface swept smooth, and depressions and hummocks or fence-row drifts formed. For range or other land it means surface soil removed, plant crown exposed, hummocks or fence-row drifts formed, and deposition covering vegetation."

Although annual damage varies widely among years, the average for the last 20 years on a state basis ranged from 1.15 million acres in Texas to 69,000 acres in Wyoming (fig. 12). More than 90 percent of the total land damaged in Montana, North Dakota, South Dakota, Kansas, and Oklahoma was cropland (fig. 12). Only Wyoming had more damage to range and other land than to cropland.

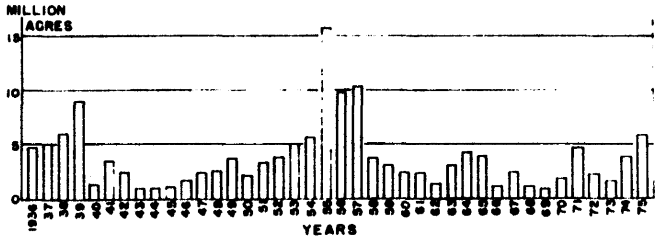

Figure 11.--Acres of land damaged annually in Great Plains, 1936-75.

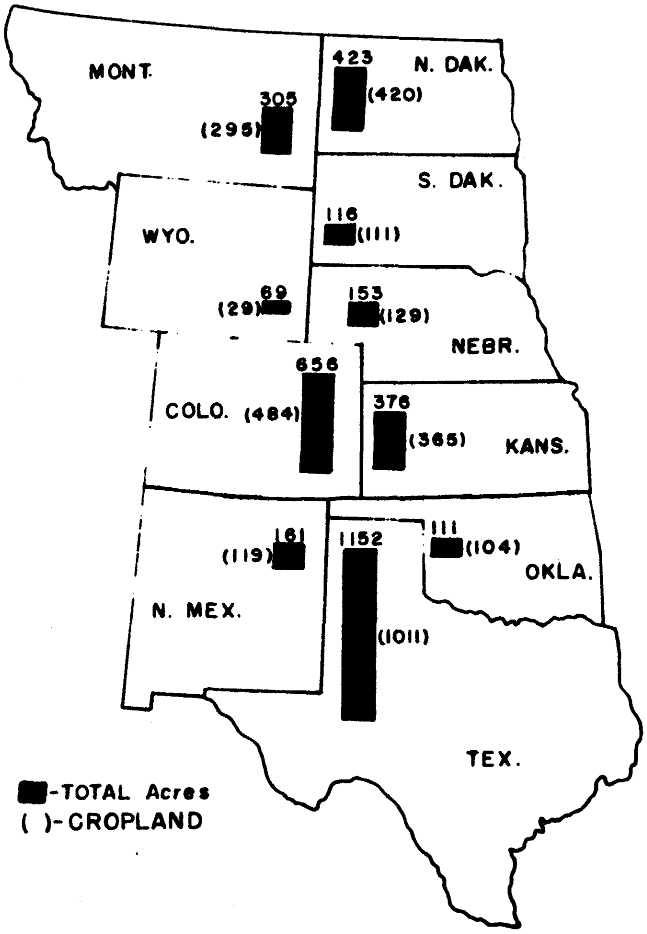

Figure 12.--Annual wind erosion damage in the Great Plains. Average for 1956-75. Acres in thousands.

Potential Annual Soil Loss

Present technology for wind erosion control uses one or more of four basic principles--establish and maintain land cover, produce stable nonerodible surface aggregates, maintain rough surfaces, and reduce field width. An empirical

3/ Soil Conservation Service unpublished reports.

wind erosion equation that considers those principles plus climate has been developed (Woodruff and Siddoway, 1965): E = f(I,K,C,L,V), where E is the potential annual soil-loss rate, I is the soil erodibility index, K is the soil-ridge roughness factor, C is the climatic factor, L is the unsheltered distance across a field along the prevailing wind direction, and V is the equivalent quantity of vegetative cover.

Using various assumptions for the equation factors, we calculated potential annual soil loss for 20 locations in the Great Plains (table 1). The assumptions used were:

I - based on wind erodibility group (WEG) (table 2)

K - constant at 0.75, midway between a smooth and rough surface

C - average for March, April, and May for each location

L - constant at 2,640 feet

V - wheat-fallow rotation with initial amounts of residue equal to 115 pounds of straw per bushel of wheat based on long-term yields by states (1928-72). Initial amounts were reduced 20 percent by overwinter loss, 50 percent by tillage, and 20 percent by second overwinter loss. Except for North Dakota and Glasgow, Montana, growing wheat, equivalent to 300 pounds per acre of flat small grain, was added to the reduced residue amounts to arrive at the equivalent vegetative cover in March of the wheat year.

Because of the many assumptions for the factors in the wind erosion equation, data in table 1 may be off by a factor of 2 but they should provide relative comparisons among different locations. Obviously, western Texas, western Kansas, and eastern Colorado are highly susceptible to wind erosion, especially the coarse-textured soils (WEG 1-3). Consequently, management of those soils is critical to reduce soil loss by wind.

SUMMARY

Graphical data, archived at the National Climatic Center, Asheville, N.C., are presented on the availability of wind data on the Great Plains.

Various factors affecting wind data credibility are identified, e.g., (1) nonuniform station density requires data interpolation or extrapolation to locations without weather stations, (2) nonstandard anemometer heights among stations limit comparisons unless corrected to a standard height, and (3) time base for wind data among stations may vary (specific years available and number of years) or be too short to describe the wind climatology of a location. Limited data indicate winds are strongest during drought years.

User requirements govern the proper reduction of wind data. Various methods are described. Prevailing wind direction must be known for proper orientation of suitable barriers. The cube of windspeed concerns wind-energy researchers and wind-erosion specialists. Nonerosive winds (below the threshold for particle movement) should be excluded from data characterizing wind erosion potential. I suggest that the next step in data refinement should be to exclude windspeeds below the threshold based on actual anemometer height rather than a constant windspeed that applies to 1 foot above the ground.

Land damaged annually by wind erosion in the 10 Great Plains states has ranged from 1 to 16 million acres, with a 40-year average of about 5 million acres. The average for the last 20 years on a state basis ranges from 1.15 million acres in Texas to 69,000 acres in Wyoming. Using various assumptions for factors in the wind erosion equation, we calculated average potential annual soil loss for different soil textures (wind erodibility groups) for 20 locations in the Great Plains. These data indicate that western Texas, western Kansas, and eastern Colorado are areas highly susceptible to wind erosion, especially the coarse-textured soils.

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Table 1.--Average potential annual soil loss for different wind erodibility groups at 20 locations in the Great Plains: wheat year of a wheat-fallow rotation.

Location	Wind erodibility groups (WEG)[1/] 1	2	3,4,4L	5	6	7
	tons/acre/year					
Bismarck, North Dakota	80	30	17	10	8	6
Minot, North Dakota	46	17	9	5	4	3
Rapid City, South Dakota	64	22	12	6	5	3
North Platte, Nebraska	55	17	8	4	3	2
Scottsbluff, Nebraska	51	16	8	4	3	2
Dodge City, Kansas	185	60	31	17	13	9
Goodland, Kansas	121	39	20	11	8	6
Wichita, Kansas	33	11	5	3	2	1
Oklahoma City, Oklahoma	35	12	6	3	3	2
Amarillo, Texas	239	85	48	27	21	16
Dalhart, Texas	348	123	68	39	30	22
Lubbock, Texas	239	85	48	27	21	16
Midland, Texas	225	79	45	25	20	15
Wichita Falls, Texas	66	23	13	7	5	4
Glasgow, Montana	44	16	9	5	4	3
Lewistown, Montana	45	14	7	4	3	2
Miles City, Montana	53	17	9	5	3	2
Cheyenne, Wyoming	65	21	11	6	5	3
Sheridan, Wyoming	32	10	5	3	2	1
La Junta, Colorado	220	79	45	26	20	16

1/ Wind erodibility groups described in table 2.

Table 2.--Descriptions of wind erodibility groups (WEG).[1/]

WEG	Predominant soil textural class	Dry soil aggregates > 0.84 mm	Soil erodibility "I"
		percent	tons/acre/year
1	Very fine, fine, and medium sands; dune sands.	1	310
2	Loamy sands; loamy fine sands.	10	134
3	Very fine sandy loams; fine sandy loams; sandy loams.	25	86
4	Clays; silty clays; noncalcareous clay loams and silty clay loams with more than 35 percent clay content.	25	86
4L	Calcareous loams and silt loams; calcareous clay loams and silty clay loams with less than 35 percent clay content.	25	86
5	Noncalcareous loams and silty loams with less than 20 percent clay content; sandy clay loams; sandy clay.	40	56
6	Noncalcareous loams and silt loams with more than 20 percent clay content; noncalcareous clay loams with less than 35 percent clay content.	45	48
7	Silts; noncalcareous silty clay loams with less than 35 percent clay content.	50	38

1/ Data from Hayes, 1972.

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