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DUST IN THE GREAT PLAINS

N. P. Woodruff, Research Leader, and L. J. Hagen, Agricultural Engineer
North Central Region, Agricultural Research Service
U. S. Department of Agriculture, Manhattan, Kansas

> All strong winds pick up much dust from the soil surface, and if loose material be plentiful, the windstorm will become a duststorm and the air so thickly filled with dust that it will be difficult to see or to breathe.
>
> -- E. E. Free (10)

Today's residents of the Great Plains will agree readily with the preceding statement by Mr. Free. Anyone who has lived in the Plains for only a short time has come to realize that it is a windy place--one climatologist has called the center of the Plains the windiest inland area in the United States (9)--and that when wind erosion occurs, the dust drastically and often dramatically affects the quality of our environment. Because of its geographical location, the Plains area is subjected to both desert and steppe kinds of duststorms. Desert storms arising in the arid basins of New Mexico, Arizona, Utah, and Southern California carry dust sometimes westward toward the Pacific but oftentimes eastward into the Plains region. Steppe storms occurring on the Plains mostly blow dust from place to place within the Plains States. In this paper we consider the why, how much, consequences, and future prospects of dust resulting from Plains duststorms.

Why?

Soil Conditions

Wind erosion is caused by a strong, turbulent wind blowing across an unprotected soil surface that is smooth, bare, loose, dry, and finely granulated (6). Soil conditions, therefore, have considerable bearing on wind erosion. Great deposits of loess and also extensive areas of sandy soils exist on the Plains. In their native states, most of those Plains soils are characteristically loose and finely granulated at the surface. Alternate wetting and drying and freezing and thawing tend to break soil clods into finer aggregates. Under natural conditions grass usually protects the fine surface material of these soils from erosion by wind. However, as soon as the grass is destroyed or the sod broken and the soil left bare, the fine surface soil becomes highly susceptible to wind erosion (5).

Kind of Agriculture

The kind of agriculture carried out in the Great Plains after sod is broken also is conducive to wind erosion. Producing wheat and sorghums on a large scale can leave wide expanses of land nearly bare during early spring when winds reach peak velocities. The drastic disturbances resulting when those kinds of crops replace natural vegetation accelerate wind erosion processes tremendously in the flat, gently undulating, treeless Plains where the sweep of the winds is almost unbroken by topographic irregularities (1).

Winds of the Great Plains

The strong winds of the Great Plains are prime movers of dust into the atmosphere (figure 1). Soil particle movement begins when wind drag and lift forces overcome gravity force (18, 30). The threshold drag force necessary to start soil movement ranges from 0.85 to 14.0 dynes/cm.^{2}, depending on soil grain diameter, density, angle of repose, and friction between other grains. Lift forces equal about 0.85 of threshold drag (4). Field soils generally do not have a definite threshold windspeed, but dune sand will begin to move when windspeed 1 foot above the surface is about 13 m.p.h. (3). Although lift and drag forces initiate particle movement, soil particles (especially fine dusts) also are forced into the airstream by impacts of the large saltating particles (4). The von Karman-Prandtl logarithmic equation describes the windspeed profile in the lower part of both wind tunnel and atmospheric boundary layers, and is given by:

$$\frac{u_z}{u_*} = \frac{1}{k} \ln \left(\frac{Z - D}{Z_0}\right)$$

where u_z is mean velocity at height Z, u_* is friction velocity defined as $(\tau_0/\rho)^{1/2}$ where τ_0 is surface wind drag and ρ is fluid density, k is von Karman's constant (0.4), D is effective roughness height, and Z_0 is a roughness parameter. With careful windspeed profile measurements, the equation can be used to compute average surface wind drag under neutral stability conditions (17).

Once particles enter the airstream near the surface, random currents moving from the surface upward will contain higher concentrations of particles than will those moving downward from above. Consequently, there is a net diffusion of particles upward as long as particle concentration near the surface is larger than particle concentration above. Because any wind strong enough to move soil is turbulent, random windspeed fluctuations--horizontal, lateral, and vertical--caused by surface roughness elements and convection from surface heating are always present. Velocities of random vertical currents usually equal 1/10 to 1/5 of the average horizontal velocity. Thus, a 10-m.p.h. wind might have a 1- to 2-m.p.h. vertical component, which is sufficient to lift soil particles up to 0.1 mm. in diameter.

In the Great Plains, erosive winds are generally southerly and have considerable capacity for moving soil, especially in the central Great Plains (figure 2). However, above the threshold windspeed, dust concentration and windspeed are not correlated, probably because surface conditions strongly control dust concentration (7, 12). Average windspeeds during duststorms in the 1950's were generally below 30 m.p.h., and below 20 m.p.h. at 20 percent of the 37 Great Plains stations analyzed (12). Thus, duststorms occur more frequently than do high-velocity winds (table 1).

Droughts

Severe wind erosion and duststorms are closely correlated with droughts (figure 3); therefore, recurrence cycles are difficult to predict.

From 1854 to 1972, major duststorms occurred 14 times. The frequency of occurrence ranged from 2 to 15 years, but 7 of the 14 storms occurred on an approximate 10-year cycle. The periods lasted 1 to 6 years; median duration was about 2.4 years.

How Much?

Wind erosion and duststorms have been common in the Plains since white man first came into the area and probably even before. Quantitative measurements of dust generally have not been made, but this excerpt from the official weather records at Dodge City, Kansas, indicates severe duststorms in that region more than 80 years ago--before cultivation began (5):

> April 8, 1890 - At 10 a.m. the dust in the air was so dense that objects could not be distinguished 100 yards off. No one who could possibly remain indoors was on the street.

Other evidences of dust during early times, and perhaps some of the first attempts at quantitative interpretation, are found in Udden's (26) estimates of solid suspended material in duststorms: 160 to 126,000 tons per cubic mile of dust. His data showed that late in the 19th century an average of 850 million tons of dust were being carried 1,440 miles each year in Western United States.

In more recent times Judson (15), in estimating worldwide sediment contributions from different sources, concluded that sediment delivered to the oceans by wind amounted to about 66 x 10^6 to 397 x 10^6 tons per year, or only about 1 percent of his estimated total delivery from all sources. He therefore considered wind erosion, compared with water erosion, volumetrically unimportant in delivering sediment to the oceans--and perhaps it is, from a worldwide geological standpoint. However, in their effects on local environment, particularly in the Great Plains, wind erosion and duststorms are extremely important. According to the 1965 National Inventory of Soil and Water Conservation Needs (8), wind erosion is the dominant problem on about 33 million acres of land in the Great Plains States, where damage 1/ from wind erosion has averaged 5 million acres per year for the past 20 years and ranged from 1 to 16 million acres during the past 35 years.

In this section we will present available information on dustloads during the 1930's and 1950's, when there was serious wind erosion on the Plains, and compare it with information on dustloads during the 1960's, when the influence of serious wind erosion was relatively slight.

Dust in the 1930's

Quantitative data on dustloads during the 1930's are meager, but the literature contains many statements on the severity of the situation.

1/ According to USDA Soil Conservation Service Wind Erosion Conditions - Great Plains "Summary of Local Estimates as of May 31, 1971, for the 1970-71 Wind Erosion Season."

For example, Lawrence Svobida, a young farmer who went through the dust-bowl days in Meade County, Kansas, in his book "An Empire of Dust" (24), describes the so-called "black blizzards" thus:

> The dust became thicker and thicker, obscuring the landscape and continuing to grow in density until vision is reduced to 1,000 yards or less. Then if this is to be a real duststorm, a typical "black blizzard" of the dust bowl, the wind continues to increase its velocity until it is blowing at 40 to 50 m.p.h. Soon everything is moving, both farmland and pasture alike. The fine dust is sweeping along at express-train speed, and when the very sun is blotted out, visibility is reduced to 50 feet. Pilots flying in these storms reported the atmosphere 2 or 3 miles up laden with dust.

Assuming the visibilities noted by Svobida to be reasonably accurate, and using relationships between visibility and dustload developed at the Wind Erosion Laboratory in the 1950's, the maximum dustload during the 1930 storms could have been about 9,800 tons per cubic mile.

Malina (19) reported that dust from a February 7, 1937, duststorm in the Texas-Oklahoma Panhandle deposited as much as 200 pounds per acre on snow in Iowa, 500 miles away. Weather records at Dodge City, Kansas, and Goodwell, Oklahoma, reveal the number of duststorms from 1933 to 1940:

Year	Dodge City	Goodwell
1933	26	70
1934	13	22
1935	51	53
1936	42	73
1937	123	117
1938	77	61
1939	102	30
1940	42	17
Av.	59.5	55.3

About the only quantitative measurements of dust concentration in the 1930's were made by Langham et al. (16) at Goodwell, Oklahoma. In sampling 29 storms in 1936 and 1937, they obtained an average concentration at the 30-inch height of 33 ± 14 mg./ft.^{3} of dust, when average windspeeds were 23.2 ± 2.5 m.p.h. Their maximum and minimum measured concentrations were 115 ± 32 and 5 ± 0 mg./ft.^{3}, respectively. Those data fit the dustload visibility relationships developed in the 1950's at our Wind Erosion Laboratory. Therefore, the dustloads associated with maximum and average measured concentrations would be 7,400 and 324 tons/mile^3, respectively.

Dust in the 1950's

Chepil and Woodruff (7) measured dust concentrations in 24 duststorms in western Kansas and eastern Colorado in the spring of 1954 and

1955. They obtained an average concentration at the 6-foot height of 6.54 mg./ft.^{3}, when average windspeeds at the 8-foot elevation were 20.8 m.p.h. Their maximum and minimum measured concentrations were 37.58 and 0.09 mg./ft.^{3}, and total dustloads associated with their maximum and average measured concentrations were 1,290 and 224 tons/mile^3, respectively.

When Hagen and Woodruff (12) analyzed hourly observations of weather on dusty days during the 1950's at 37 weather stations in the Great Plains, they noted that Dodge City, Kansas, averaged 22.6 dusty days per year in that decade, compared with 59.5 days per year in the 1930's. Visibility and dust concentration and hours and days of dust for all 37 stations during the 1950 decade are summarized in the cumulative-frequency distribution curves of figures 4 and 5. Median concentration was 4.85 mg./m.^{3}, but approximately 4 percent of the observations had concentrations exceeding 100 mg./m.^{3}. Median annual hours of dust was 45, but more than 150 dusty hours were recorded in 20 percent of the reports. Also, in the 1950's the average duststorm lasted 6.6 hours and involved areas averaging 188 square miles. Wind erosion contributed an average of about 244 million tons per year of dust to the atmospheric particulate load--far exceeding the 30 million tons per year commonly used as wind erosion's contribution to the air pollution load (27).

Dust in the 1960's

Smith et al. (22, 23) and Twiss (25) operated a network of dust-trapping sites (including 10 stations in the Great Plains) from 1963 to 1967 to obtain information on dust-deposition rate. They found that the mean monthly deposition rate ranged from 7 pounds per acre in December at Akron, Colorado, to 1,164 pounds per acre in May at Tribune, Kansas; they estimated that the years required to deposit 1 acre-inch of sediment would range from 91 at Tribune, Kansas, to 1,245 at Water Valley, Texas, (table 2). The low dust-deposition rates at Water Valley suggest that much of the dust suspended from sandy soils located only a short distance northward is swept predominantly northward and northeastward by the prevailing southerly winds and occasional cyclonic storms. That tendency of mid-latitude dust-deposition rates to decrease eastward along the central storm tracks is shown in figure 6. Rates decrease most rapidly between Tribune and Hays, Kansas, but continue to decrease eastward to Coshocton, Ohio, about 1,025 miles from Tribune. Beyond that point the relation to distance from western Kansas is lost, in that rates increase at Marcellus and Marlboro.

Correlation analyses by Smith et al. (23) showed positive relations between dust-deposition rates and some power of monthly windspeed and rainfall, suggesting that considerable sediment is carried down by precipitation. Using windspeed, rainfall, and various seasonal parameters (though not necessarily the same ones for all locations), they also developed several multiple regression equations to predict monthly dust deposition. For example, for Tribune, Kansas, they developed this equation:

$$Y = -493 + 192X_1 + 8.0X_2 + 0.2875X_3{}^4$$

where Y = monthly deposition rates in pounds per acre
X_1 = Dodge City, number of 3-hour-interval occurrences of dust
X_2 = Tribune, monthly rainfall in mm.
X_3 = Dodge City, average windspeed in m./sec.
But for Manhattan they developed this equation:

$$Y = -15.4 + 0.074_1{}^3 + 0.021X_2{}^4 + 4.5X_3$$

where Y = monthly deposition rate in pounds per acre
X_1 = Goodland, previous month average windspeed in m./sec.
X_2 = Dodge City, current month average windspeed in m./sec.
X_3 = number of days with rainfall $\geq$ 2.54 mm.

To determine dustloads during a period of relatively little wind erosion (the 1960's), Hagen and Woodruff (12) analyzed available data from 12 selected Southern Great Plains stations. (One of the stations, Dodge City, Kansas, averaged only 6.9 dusty days per year in the 1960's compared with 59.5 and 22.6 dusty days per year during the 1930's and 1950's, respectively.) As summarized in table 3, average dust concentration for all 12 stations during the 1960's dropped about 24 percent from the 1950 average. Similarly, there was a 78.6 percent decrease in dust passage during the 1960's compared with the 1950's. Maximum dust passage occurred at Goodland, Kansas, where it averaged 246,000 tons per vertical square mile annually during the 1950's but dropped to about 81,000 tons annually in the 1960's. Estimates from these dust-passage data of the total dust-particulate load suspended by wind erosion for the 1960's are 77 million tons annually, or about 69 percent less than the 244 million tons per year estimated during the 1950's, a decade of more serious wind erosion.

Those estimates of total particulate loading can be compared with measurements of dust deposition by Smith et al. (23) from 1964 through 1966 for 5 stations in the Great Plains--North Platte, Nebraska; Hays and Manhattan, Kansas; and Riesel and Water Valley, Texas. Smith et al. measured 547 kilograms per hectare per year of dust deposited on the land surface. For this same period we would estimate 480 kilograms per hectare per year suspended. The nearness of these calculations provides creditability to the method used to estimate the total dustload.

Consequences

Lawrence Svobida closed his book "An Empire of Dust" (24), written in 1938 after he had endured 9 years of extreme hardship in the dust bowl at Meade, Kansas, with, "My own humble opinion is that with the exception of a few favored localities, the whole Great Plains region is already a desert that cannot be reclaimed through the plans and labors of man." Dr. Cecil H. Wadleigh (27) used the ditty, "May the gusty wind that blows the ladies skirts knee-high also blow dust in the naughty man's eye," to say that this probably represents the only case wherein a benefit has been attributed to airborne dusts in day-to-day living. We now know that even the serious wind erosion of the dust-bowl days did not completely ruin the land, as Svobida had thought, but we also know that perhaps the benefits of wind erosion and blowing soil may very well be limited to those cited in the Wadleigh ditty.

Generally wind erosion, blowing soil, and dust have a bad effect on our environment. Because dust often travels thousands of miles, all people are affected--urban and rural. Airborne soil, polluting the air we breathe, is both an irritant and health depressant. When blowing dust becomes so dense as to be classed a "black blizzard," as it was in the 1930's, it kills livestock, birds, wild game, and humans--1,600 people are estimated to have died from the effects of dust and heat during 1936 (24). Blowing dust also obscures visibility and interferes with air traffic, causes automobile accidents, fouls machinery bearings and electrical switching apparatus, and deposits dust in homes, offices, schools, and stores. It also sandblasts, abrades, and kills plants and thereby reduces the quantity and quality of our food supplies. Left uncontrolled, it buries irrigation ditches, fences, and roads. By removing soil from its source, wind erosion also ruins agricultural land, and it reduces crop yields by removing silt, clay, organic matter, and plant nutrients. The result can be economic disaster to individuals and, in extreme cases, to whole societies.

Future Prospects

Where do we stand today? Are we now--through research and its application by the Soil Conservation and Extension Services; through more knowledgeable farmers with better attitudes than in the 1930's and 1950's; through irrigation, better farm machinery, plans for artificially increasing precipitation; and through government conservation programs--at a stage we can control wind erosion, recalling the dust bowl only as a sad memory? Or will we continue to have wind erosion and a badly polluted environment and possibly even another dust bowl and economic disaster?

Data presented in this paper show that substantial quantities of dust move into the atmosphere even during the so-called "good" years. Since 1953 the Big Spring, Texas, area has averaged 27 days per year with blowing dust (11), which shows that we have not yet solved the problem, cannot relax our efforts, and perhaps ought to think about developing effective land-use policies. Even though indications are the dust bowl days will not be repeated, no one knows exactly what would happen if the entire Plains area should have a drought worse than any previous one. Some, like U. S. Weather Service Climatologist Lothar Joos (14), believe that widespread irrigation of the Plains has so changed the climate that there will be more rainfall and, therefore, no serious droughts. Others, however, believe that the large acreages of soil that have been put under irrigation, especially under the center pivot systems, are highly susceptible to wind erosion and may well be as serious a source for dust in the air as are dryland soils (21).

The Congress of the United States has passed the Clean Air Act. The Environmental Protection Agency (EPA) is charged with carrying out the various provisions of this Act. The States, however, are given an opportunity to assume responsibility for establishing standards defining the ambient air quality in terms of average and maximum quantities of specific pollutants that will be permitted (28). Should they fail to accept this responsibility, then control and abatement actions are transferred to the Federal Government.

Several States (e.g., Iowa 2/ and Kansas 3/) already have developed standards for sulfur dioxide, particulates, carbon monoxide, total oxidants, and hydrocarbons. The States apparently are taking two different approaches to control particulates: (a) to establish standards as a function of land use, or (b) to establish uniform requirements regardless of location. Iowa has proposed standards using approach (a), where directors of conservation districts will have power to take legal action to stop erosion. We cannot now meet air-quality criteria for particulates; hence, we must do a better job of controlling soil blowing than we have in the past 4/. If we may judge from the relatively "tough" measures taken by EPA to enforce water-quality standards, it seems not unreasonable to believe that suitable abatement practices could be enforced by such measures as withholding payment of subsidies and refusing to grant government-insured loans to individuals or areas.

We have made substantial progress in controlling wind erosion and dust. Thirty-four percent of this country's 70 million acres having wind erosion as its dominant problem is now adequately protected by good farming practices. Special wind-erosion control practices such as stripcropping, shelterbelts, and emergency tillage adequately protects an additional 59 percent of these 70 million acres; so, on the average, only about 7 percent of the 70 million acres blow each year and contribute dust to the atmosphere. We believe we have the knowledge and technical skills to reduce the percentage still more. Perhaps we will never solve the problem completely, but we can have relatively clean air in the Plains.

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Table 1.--Sixty-foot-elevation windspeeds and recurrence intervals in the Central Great Plains.

Duration period	Recurrence interval 2 years	10 years	50 years
	---------- m.p.h. ----------		
1 hour	43	49	55
3 hours	41	47	53
12 hours	35	40	45
1 day	30	36	40
3 days	24	29	34

Data from Zingg (27)

Table 2.--Mean monthly and projected dust deposition rates for five Great Plains locations based on measured rate from 1963-1967 and bulk density of 1.325, i.e., deposited soil weighing 150 tons per acre-inch.

Month	Tribune, Kansas	Akron, Colorado	North Platte, Nebraska	Sidney, Montana	Water Valley, Texas
	---------- Lbs./acre ----------				
Jan.	33	7	15	16	23
Feb.	64	19	24	18	27
Mar.	436	25	33	11	34
Apr.	656	49	52	23	28
May	1,164	189	131	43	36
June	400	109	137	43	14
July	190	129	86	98	11
Aug.	122	82	35	22	23
Sept.	95	38	34	20	9
Oct.	57	12	26	10	10
Nov.	28	18	24	9	14
Dec.	39	7	45	65	12
Yearly totals	3,284	684	642	378	241
Number of years to deposit 1 acre-inch	91	439	468	794	1,245

Data from Twiss (24).

Table 3.--Average dustload and dust passage for 12 selected Southern Great Plains locations for the 1960's as compared with the 1950's.

Location	Dustload 1950's	Dustload 1960's	Dust passage 1950's	Dust passage 1960's
	tons/mile^3		1,000 tons/vertical mile^2	
Denver, Colorado	7.6	10.2	11.8	2.9
Pueblo, Colorado	22.1	4.4	48.3	1.2
Dodge City, Kansas	13.9	16.0	92.5	25.1
Goodland, Kansas	30.7	21.8	246.1	80.7
Topeka, Kansas	5.7	3.3	6.6	0.3
Wichita, Kansas	6.7	7.3	29.9	5.2
Oklahoma City, Oklahoma	9.1	3.5	27.1	8.8
Tulsa, Oklahoma	5.2	3.9	2.3	1.0
Amarillo, Texas	12.8	6.9	132.9	10.2
Corpus Christi, Texas	6.3	5.2	17.2	1.0
Midland, Texas	12.5	6.9	80.8	15.2
San Angelo, Texas	8.7	7.0	40.3	5.9
Average	13.4*	10.2*	61.3	13.1

* A weighted average found by weighting the station concentration by the number of hours at that concentration.

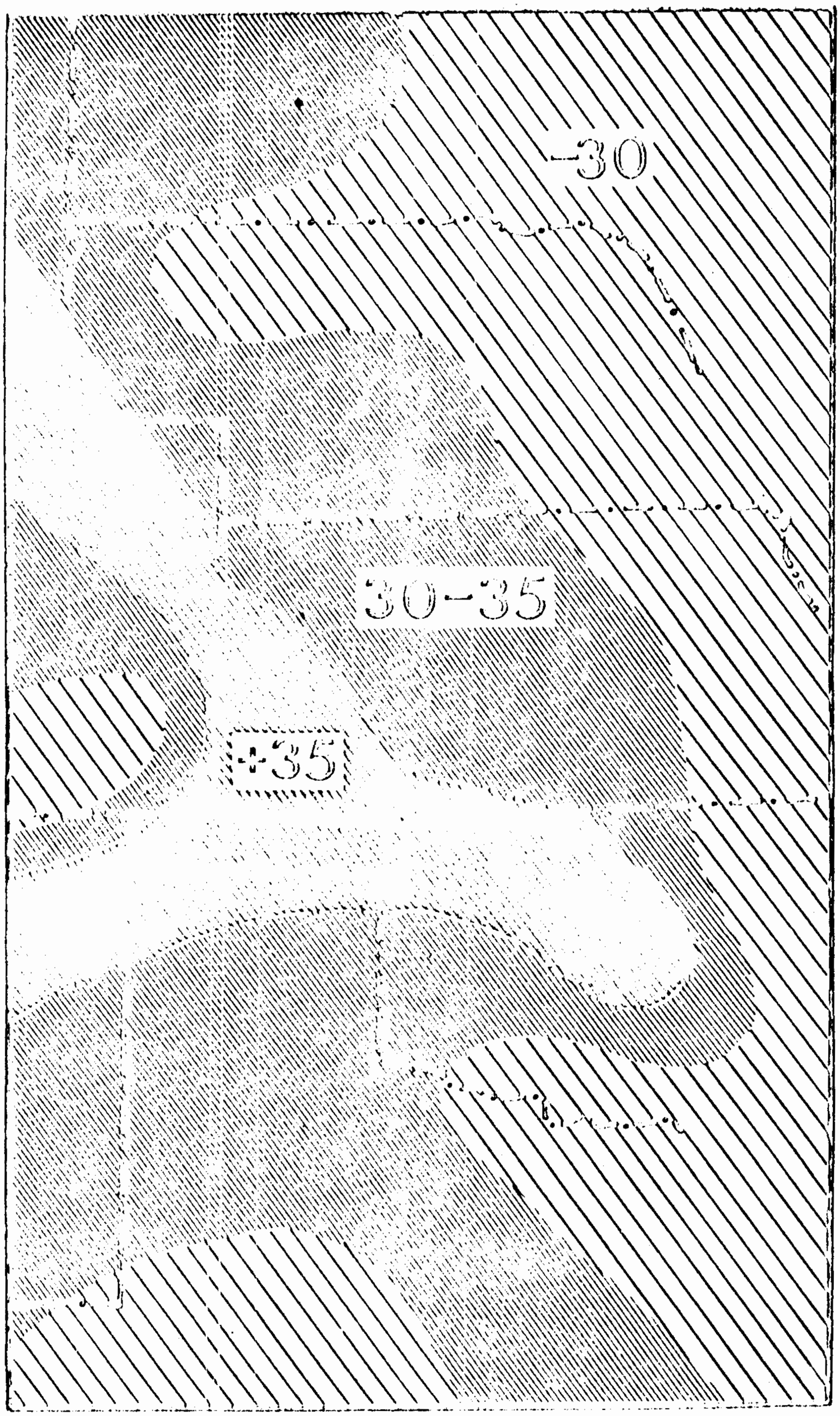

Figure 1.--Relative windiness in the Great Plains, as shown by areas in which March windspeeds of less than 30, 30 to 35, and over 35 m.p.h. (corrected to 35 feet above ground) are exceeded 2 percent of [illegible] (13).

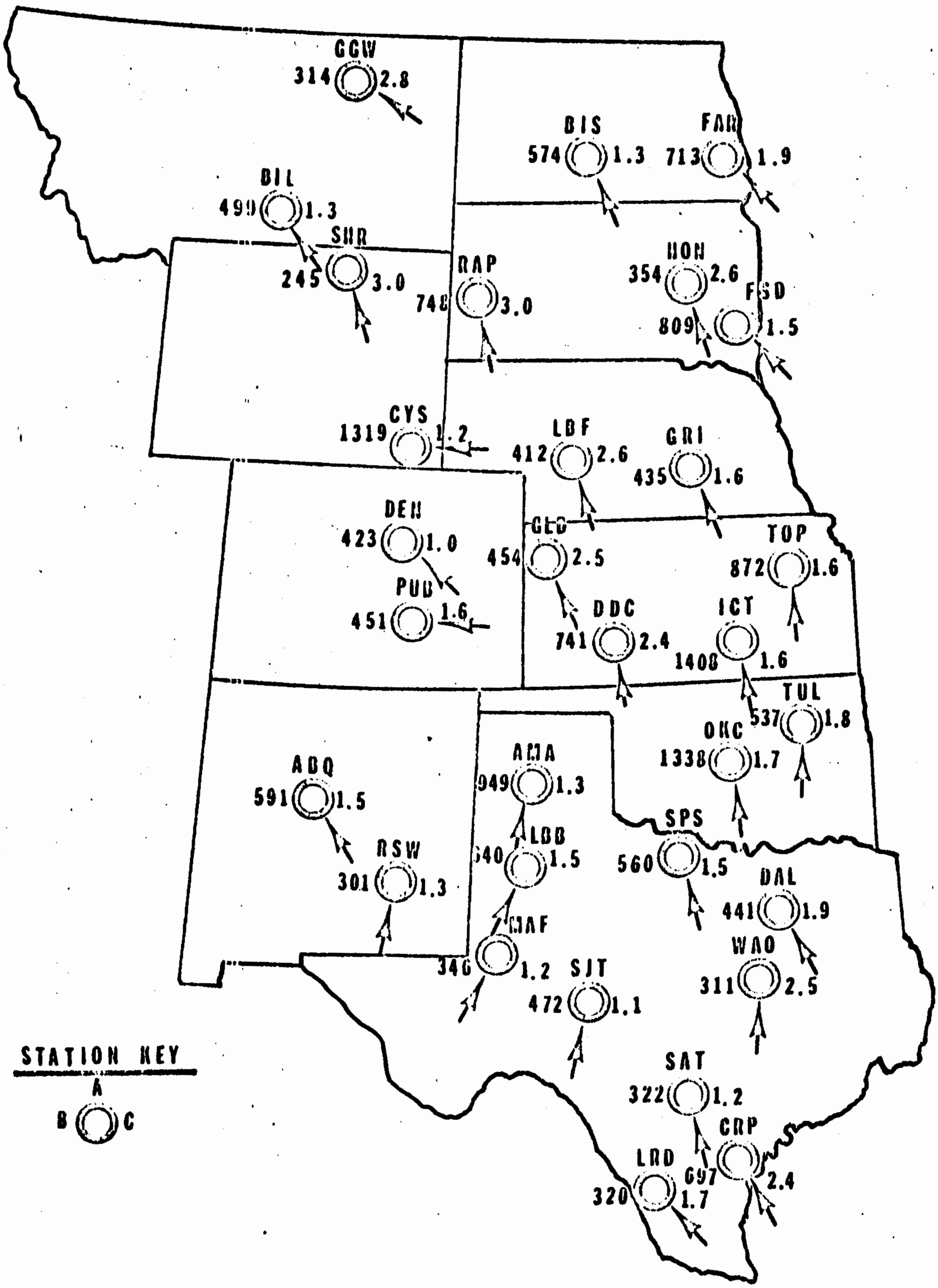

Figure 2.--Map of stations in Great Plains showing station abbreviation A; magnitude of wind erosion forces B, i.e., relative capacity to move soil; and preponderance of wind erosion forces C, i.e., prevalance of prevailing wind erosion direction shown by arrow. Data from Skidmore and Woodruff (20).

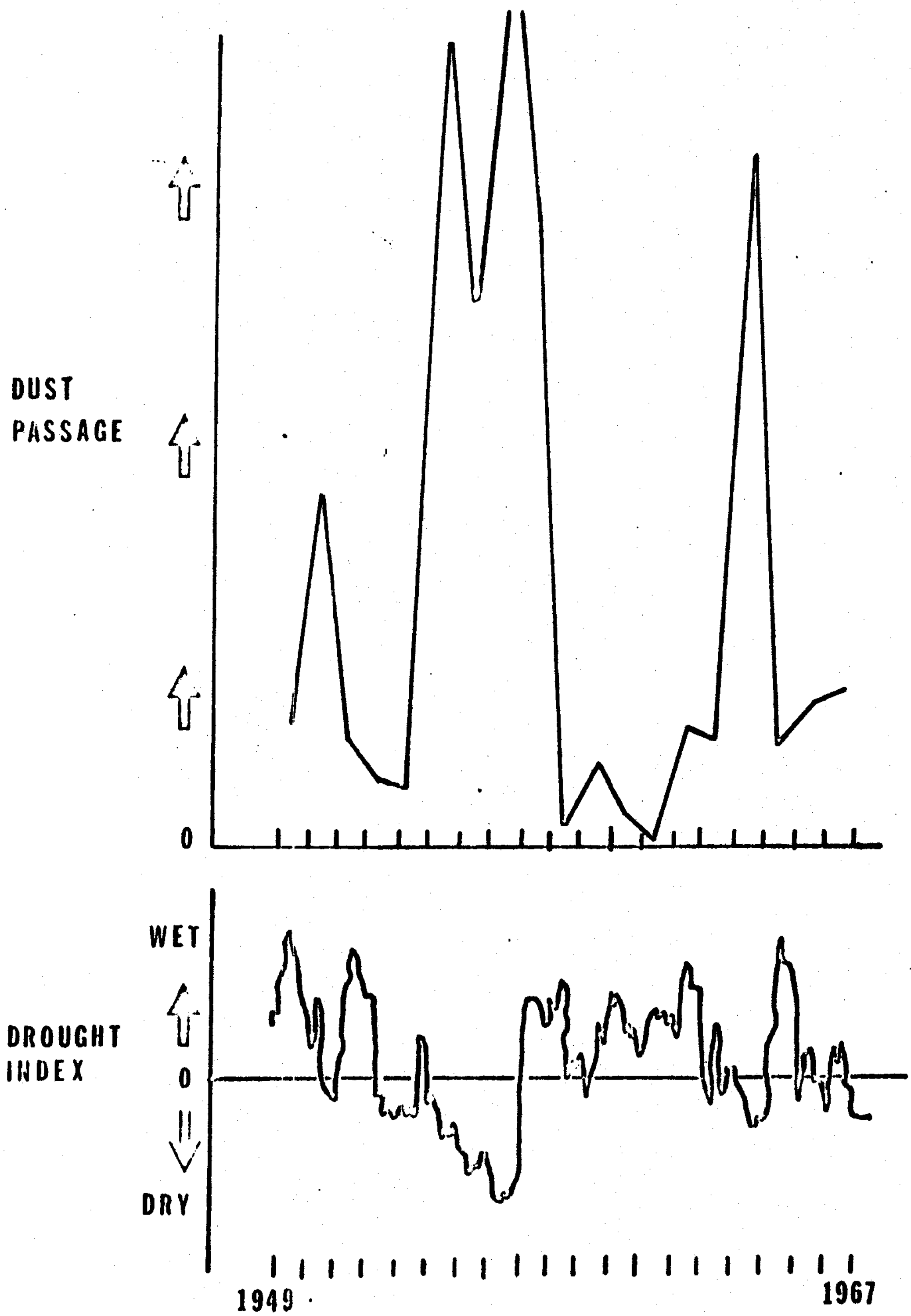

Figure 3.--Correlation of dust passage and drought index for north-west Kansas. Drought index data from Brown and Bark (2).

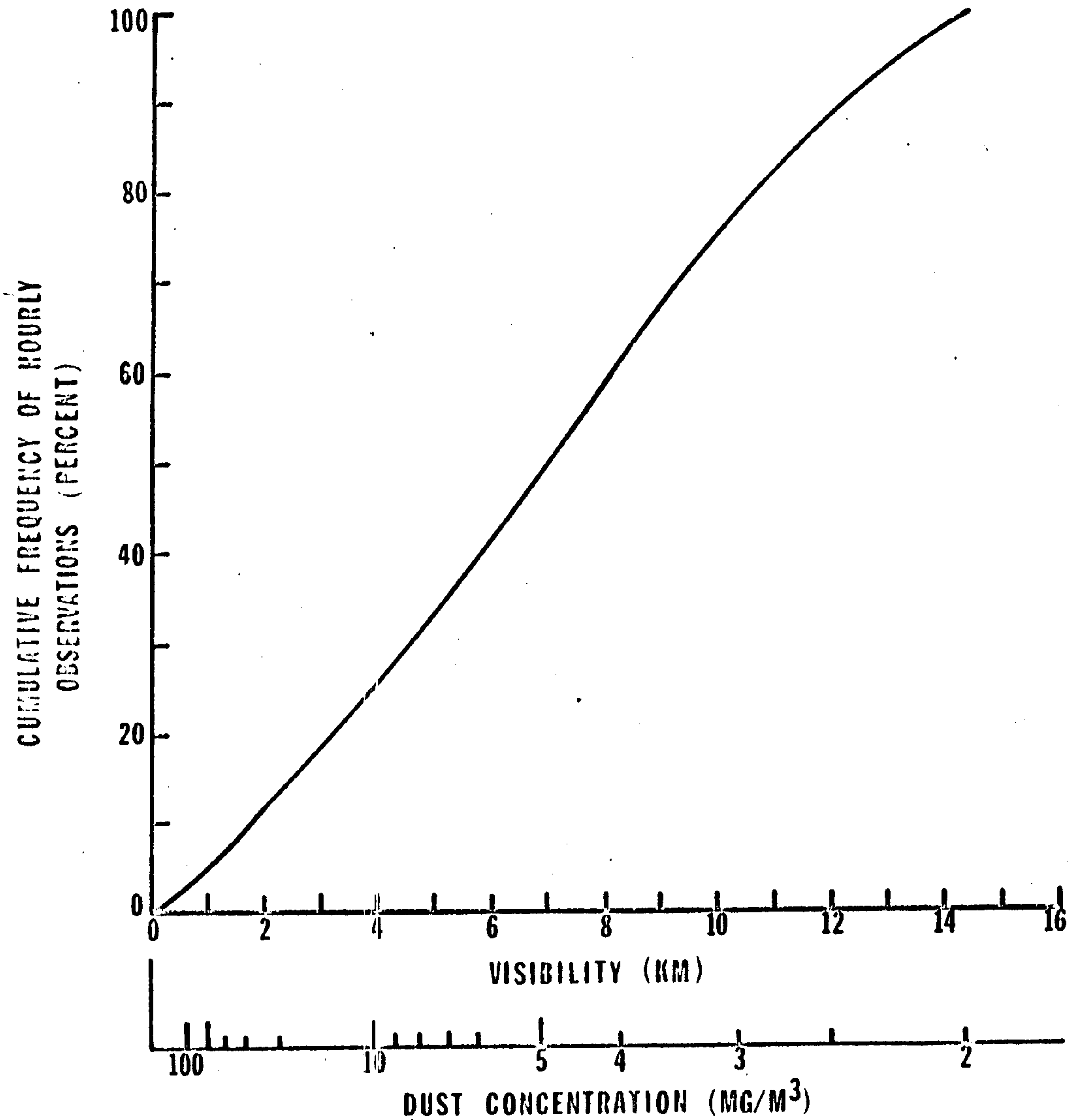

Figure 4.--Cumulative frequency distribution for more than 30,000 hourly visibility observations and computed dust concentrations during dusty hours in the 1950's at 37 Great Plains Stations. Data from Hagen and Woodruff (12).

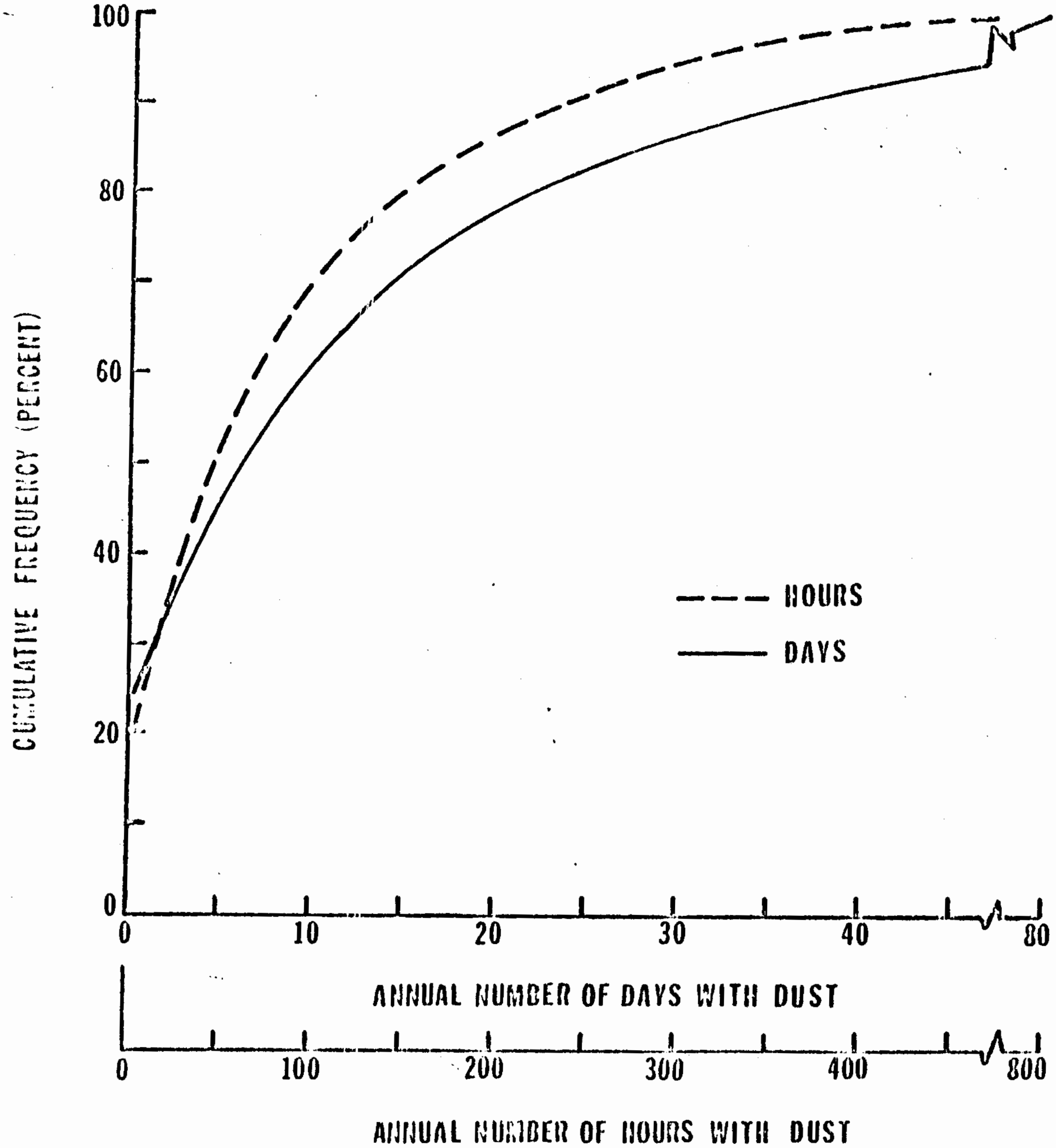

Figure 5.--Cumulative frequencies of annual number of hours and days of dust at 37 Great Plains Stations during 1950's (370 observations for each curve). Data from Hagen and Woodruff (12).

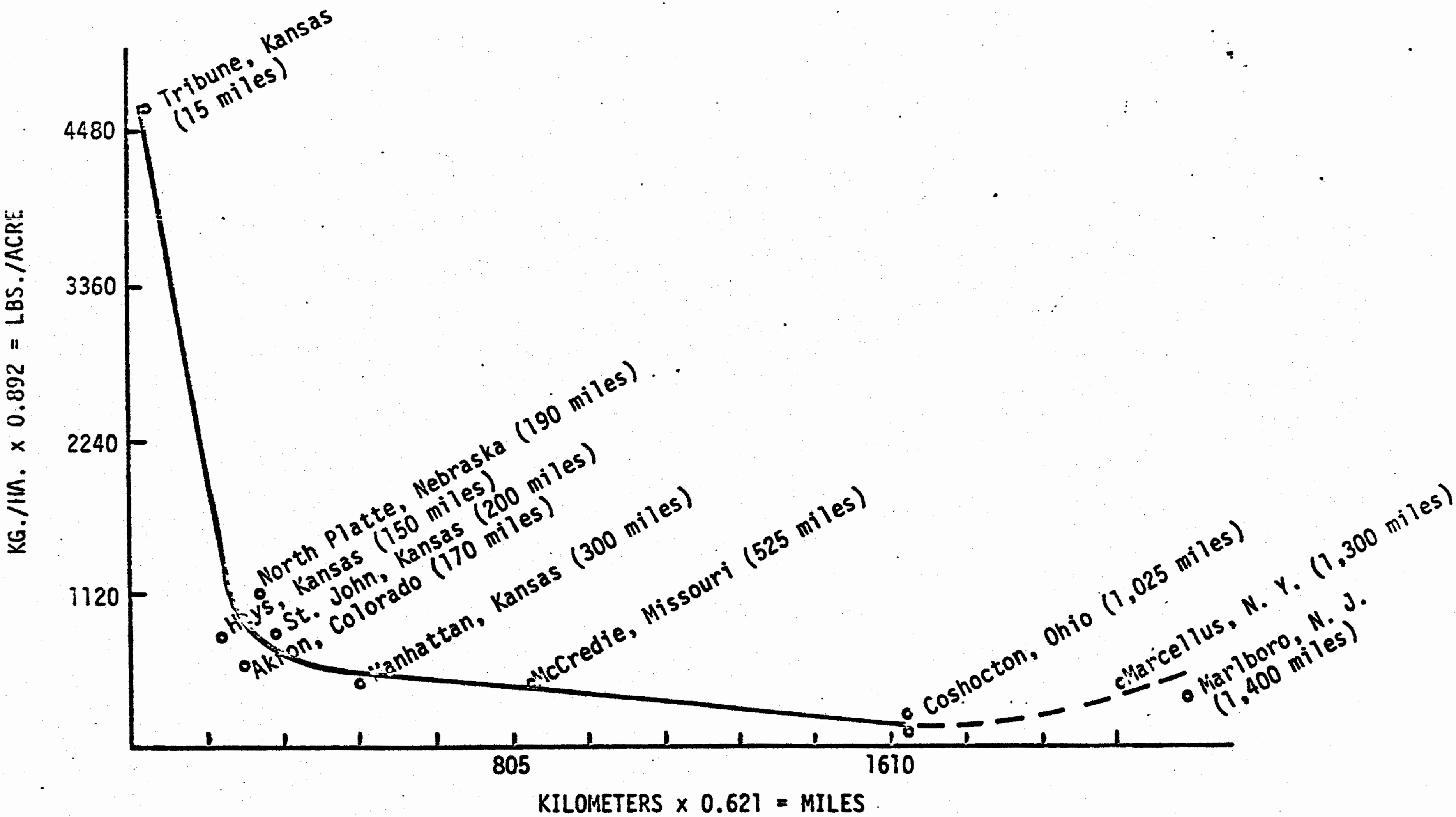

Figure 6.--Average annual dust deposition at several sites in relation to distance north and east from arbitrary dust bowl. Data from Smith et al. (23).