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AIR POLLUTION FROM DUSTSTORMS IN THE GREAT PLAINS*

L. J. HAGEN and N. P. WOODRUFF†

Southern Plains Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Manhattan, Kansas

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Abstract—Great Plains states are adopting air pollution regulations to limit particulate concentrations. Because little information is available about duststorms, an important source of particulates in those states, hourly observations of the weather on dusty days during the 1950's at 37 weather stations were analyzed. Wind direction was southerly, and windspeeds were usually 8.9–13.4 m s^{-1} (20–30 miles h^{-1}); relative humidity was less than 70 in 92 per cent of the dusty hours. During periods of low precipitation, most Great Plains locations have a significant number of hours with dust. Our study revealed that the median annual hours of dust was 45, but more than 150 dusty hours were recorded in 20 per cent of the reports. Though urban air pollution episodes last longer than duststorms, duststorms have larger particles and higher particulate concentrations. We found the average duststorm lasted 6.6 h, and median dust concentration was 4.85 mg m^{-3}. Because of high concentrations of coarse particles in duststorms, air pollution laws in the Great Plains probably should specify particulate size distributions to which various sections of the laws apply as well as limits on particulate concentrations.

INTRODUCTION

EXCESSIVE amounts of particulates in the atmosphere can affect the safety, health, and economic well-being of man (NAPCA, 1969). Consequently, most Great Plains states are adopting air pollution laws that specify limits on particulate concentrations (e.g., KANSAS STATE DEPARTMENT OF HEALTH, 1972). Air pollution usually is considered an urban problem, but dust suspended by wind erosion also is a source of particulates to be considered in formulating realistic air pollution laws. Little information is available on duststorms, however, so we estimated the frequency and particulate concentration of duststorms in the Great Plains.

The average, annual particulate concentration at most Great Plains locations is low. Random, single-day samples taken during each 2-week period for several years by the National Air Surveillance Networks showed that long-term, geometric mean concentrations range from about 10 to 140 μg m^{-3} at Great Plains locations but that concentrations are high during duststorms (NAPCA, 1970). For example, in March 1963 a concentration of 843 μg m^{-3} above the 10-y mean (which is about 26 μg m^{-3}) was recorded in Ward County, North Dakota, during a duststorm. Hence, wind erosion tends to produce short-term, high-concentration particulate loads.

THEORY

To estimate particulate concentration during duststorms, some parameter related to particulate concentration should be measured frequently. Recent research

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† Agricultural Engineer and Research Investigations Leader, Soil Erosion, respectively, USDA, Manhattan, Kansas.

(NAPCA, 1969; CHARLSON, 1969) has shown that atmospheric visibility and particulate concentration are related when the particle size distribution remains constant and the relative humidity is less than 70 per cent or deliquescent particles are not present in significant numbers.

CHEPIL (1957) observed that particle-size distribution measured during duststorms apparently remained log-normal over various soil textures (FIG. 1). This is not surprising, however, because wind erosion is a kind of comminution process, and comminution processes commonly produce log-normal particle-size distributions. Also,

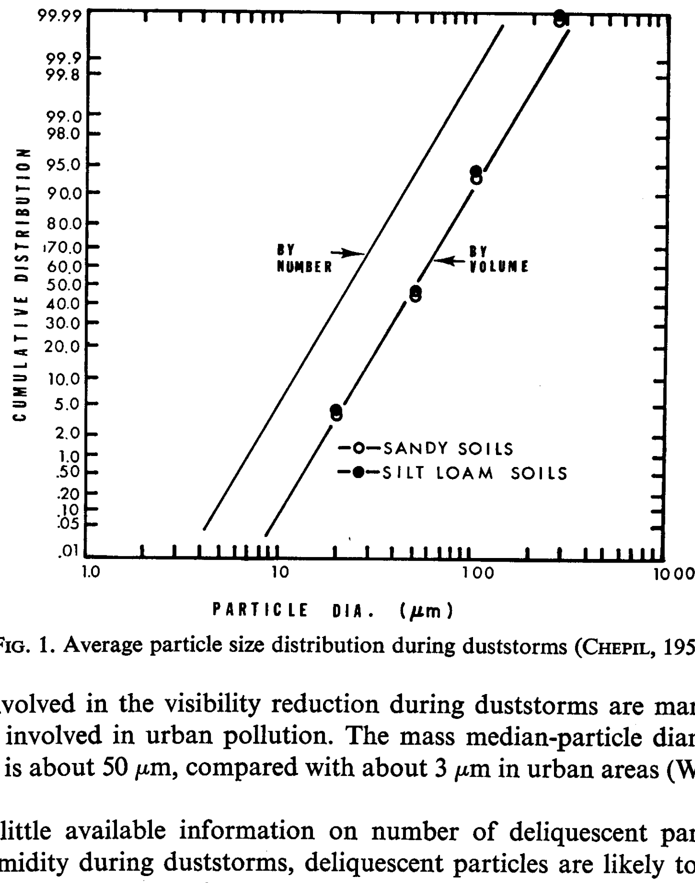

FIG. 1. Average particle size distribution during duststorms (CHEPIL, 1957).

particles involved in the visibility reduction during duststorms are markedly larger than those involved in urban pollution. The mass median-particle diameter during duststorms is about 50 μm, compared with about 3 μm in urban areas (WHITBY *et al.*, 1957).

Despite little available information on number of deliquescent particles or on relative humidity during duststorms, deliquescent particles are likely to be few and widely dispersed (because of meteorological conditions) and the relative humidity (as shown in the results section) generally is low.

From simultaneous visibility and dust-concentration measurements during duststorms, CHEPIL and WOODRUFF (1957) found that dust concentration at 6 ft above the surface was related to visibility by

$$C_6 = \frac{56.0}{V^{1.25}} \text{ [mg m}^{-3}\text{]}, \tag{1}$$

where V is horizontal visibility in km (FIG. 2). Using formulations from ROBINSON (1968), a theoretical visibility-concentration relationship can be computed for the

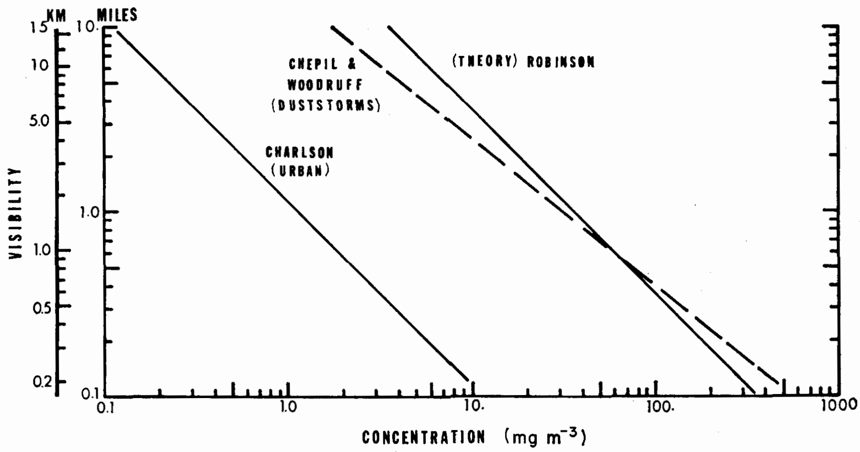

FIG. 2. Visibility related to particulate concentration for various conditions.

case where the particles are of uniform size and scattering alone accounts for the visibility extinction. In this case

$$C = \frac{5.2\ \rho r}{VK}\ [\mathrm{mg\ m^{-3}}], \tag{2}$$

where density (ρ) is about 2 g cm^{-3}, particle radius (r) is 11 μm at geometric mean by number, visibility (V) is in km, and scattering area coefficient (K) is about 2 for large particles. Then

$$C = \frac{57.2}{V}\ [\mathrm{mg\ m^{-3}}]. \tag{3}$$

This theoretical concentration-visibility relation agrees with the measured relation where V is 0.97 km, but it has a larger concentration than measured for visibilities greater than 0.97 km. Because scattering-area coefficients are large for the small particles found in urban areas, it takes a much smaller concentration of such particles to reduce visibility than it does of dust particles during duststorms (ROBINSON, 1968). Thus the concentrations found by CHARLSON (1969) were much lower than those observed during duststorms at the same visibilities (FIG. 2).

PROCEDURE

To study frequency and particulate concentrations of duststorms, we obtained, from National Weather Service records, hourly weather observations for each day that dust or blowing dust was reported (for 10 consecutive years, beginning with either 1949 or 1950) at 37 Great Plains weather stations. We analyzed these data. (For stations at which 1959 dust data were used, the average 1959 precipitation was above the record mean and nearly equaled the 1949 precipitation. Thus, use of 1959 data instead of 1949 data at those stations should not alter results.)

Particulate concentrations were estimated using the visibility observations and the experimental relationship shown in equation (1). Because visibility obstructions are not reported when visibility is 11.3 km (7 miles) or greater, dust was assumed to be the visibility obstruction on dusty days when visibility ranged from 11.3 to 14.5 km (7–9 miles) and windspeed exceeded 5.4 m s^{-1} (12 miles h^{-1}).

RESULTS AND DISCUSSION

Weather during duststorms

Stations and the periods analyzed are shown in TABLE 1. Two stations, located in largely uncultivated areas, reported no days with dust observations. All others reported dust, with windspeeds during duststorms usually averaging between 8.9 and 13.4 m s^{-1} (20 and 30 miles h^{-1}), although 20 per cent reported average windspeeds of less than 8.9 m s^{-1} (20 miles h^{-1}). Two stations reported average windspeeds exceeding 13.4 m s^{-1} (30 miles h^{-1}) during duststorms; located in generally non-erosive areas, they contributed a total of only 8 days with dust. Maximum windspeeds reported ranged from 17.9 to 34.9 m s^{-1} (40–78 miles h^{-1}). With rare exceptions, the resultant wind direction was southerly during duststorms.

Relative humidity, usually low during duststorms, exceeded 70 per cent during only 8 per cent of the dusty hours in the 1950's (FIG. 3). Visibilities of 4.8 km (3 miles) or less, reported for 33 per cent of the dusty hours, were accompanied by relative humidities greater than 70 per cent during less than 2 per cent of the dusty hours. Thus, high relative humidity is seldom present to aid in reducing visibility during duststorms.

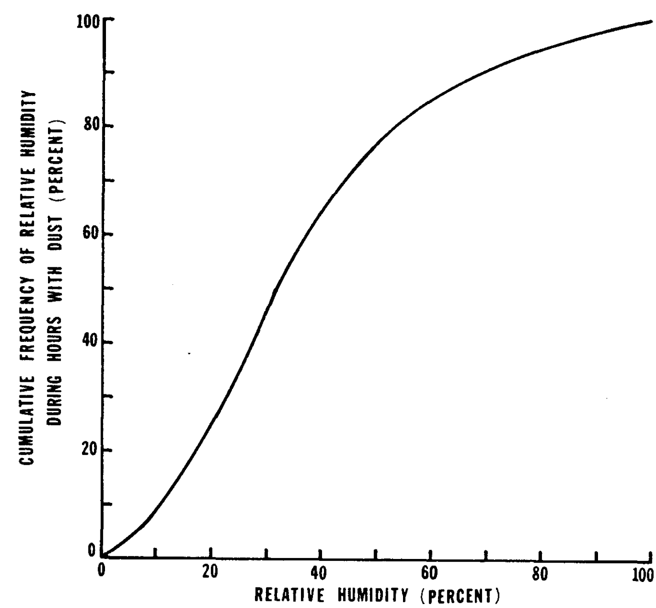

FIG. 3. Cumulative frequency of relative humidity during hours with dust in the 1950's at 37 Great Plains stations.

Varying precipitation caused large changes in annual average number of dusty hours (FIG. 4). However, annual precipitation and annual dusty hours are not well

TABLE 1. STATIONS, PERIODS AND WINDSPEED DATA SUMMARIZED

Station name	Station abbreviation	Period	Average windspeed*	Resultant wind direction*
		(month/y)	(m s^{-1})	(0°)
El Paso, Tex.	ELP	1/49–12/58	11.0	214
Amarillo, Tex.	AMA	1/50–12/59	10·3	169
Laredo, Tex.	LRD	1/49–12/58	7.7	166
San Antonio, Tex.	SAT	1/49–12/58	6.7	168
Corpus Christi, Tex.	CRP	1/50–12/59	8.9	141
Waco, Tex.	WAO	1/50–12/59	8.4	230
Dallas, Tex.	DAL	1/49–12/58	7.2	236
Abilene, Tex.	ABI	1/49–12/58	9.1	207
Wichita Falls, Tex.	SPS	1/49–12/58	9.0	200
Midland, Tex.	MAF	1/50–12/59	8.8	165
San Angelo, Tex.	SJT	1/50–12/59	9.5	191
Lubbock, Tex.	LBB	1/49–12/58	11.7	194
Roswell, N. Mex.	RSW	1/49–12/58	12.0	195
Albuquerque, N. Mex.	ABQ	1/49–12/58	11.6	201
Oklahoma City, Okla.	OKC	1/50–12/59	11.2	193
Tulsa, Okla.	TUL	1/50–12/59	8.2	204
Goodland, Kan.	GLD	1/49–12/58	10.3	216
Dodge City, Kan.	DDC	1/49–12/58	12.2	185
Topeka, Kan.	TOP	1/50–12/59	10.3	228
Wichita, Kan.	ICT	1/49–12/58	11.5	213
Denver, Colo.	DEN	1/50–12/59	12.1	136
Grand Junction, Colo.	GJT	1/49–12/58	11.4	202
Pueblo, Colo.	PUB	1/50–12/59	12.0	139
North Platte, Nebr.	LBF	1/49–12/58	9.7	195
Grand Island, Nebr.	GRI	1/49–12/58	11.2	198
Norfolk, Nebr.	NFK	1/49–12/58	12.5	220
Cheyenne, Wyo.	CYS	1/49–12/58	9.3	177
Sheridan, Wyo.	SHR	1/49–12/58	10.6	285
Casper, Wyo.	CPR	3/50– 2/60	14.7	205
Rapid City, S. Dak.	RCA	1/49–12/58	No dusty days	
Sioux Falls, S. Dak.	FSD	1/49–12/58	10.9	220
Huron, S. Dak.	HON	1/49–12/58	11.9	218
Bismarck, N. Dak.	BIS	1/49–12/58	10.8	239
Williston, N. Dak.	ISN	3/50– 2/60	9.8	240
Fargo, N. Dak.	FAR	1/49–12/58	12.4	229
Billings, Mont.	BIL	1/49–12/58	23.4	325
Glasgow, Mont.	GGW	1/50–12/59	No dusty days	

* Based on hourly observations during dusty days when (a) visibility was less than 11.3 km (7 miles) and dust was reported and (b) visibility was 11.3–14.5 km (7–9 miles) and the windspeed exceeded 5.4 m s^{-1} (12 miles h^{-1}).

related (coefficient of determination $(r^2) = 0.38$), because the spring following a year with low precipitation usually has many duststorms. Consequently, annual number of dusty hours is related more closely to 2-y mean precipitation than single-year precipitation, as illustrated by the open circles and regression line in FIG. 4

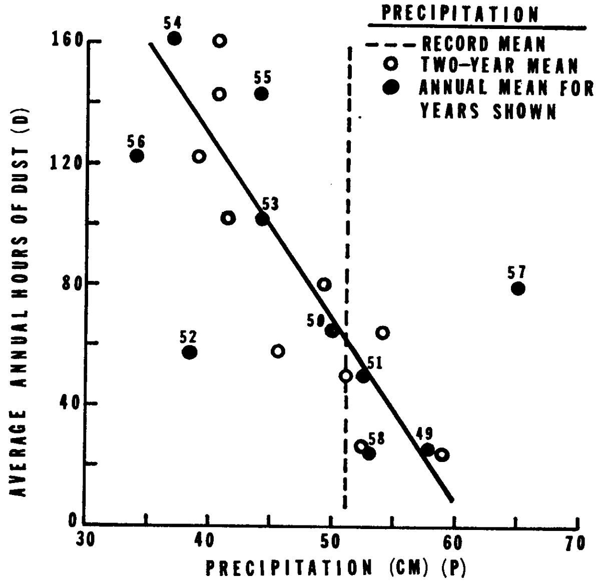

FIG. 4. Annual and 2-y mean precipitation related to annual hours of dust at 37 Great Plains stations in 1950's. (Regression line is based on 2-y precipitation means using year of dust data and previous year; equation is $D = 369.3 - 6.05$ P).

($r^2 = 0.76$). The Great Plains had a drought in the mid-fifties but above-normal precipitation in the early and late fifties. Average annual hours of dust ranged from 24 in 1958 to 161 in 1954.

DUSTSTORM FREQUENCY AND PARTICULATE CONCENTRATION

Equation one was used to compute hourly dust concentrations. Reports of zero visibility were set equal to 0.10 km ($\frac{1}{16}$ mile) to avoid division by zero. Permissible dust concentrations then ranged from 1.98 to 988 mg m^{-3} at 14.48 and 0.10 km (9 and $\frac{1}{16}$ mile) visibilities, respectively. Using those limits, the median hourly dust concentration was 4.85 mg m^{-3} during dusty hours in the 1950's (FIG. 5). The frequency distribution, nearly linear over the range of visibilities involved, indicated about equal numbers of observations in each increment of visibility.

Average dust concentrations ranged from about 5 to 10 mg m^{-3} in the least erosive areas (TABLE 2). In the driest area of the Southern Great Plains, however, average dust concentrations were usually 10–15 mg m^{-3} during duststorms. Such dust concentrations are large, compared with the 1 mg m^{-3} concentrations considered severe in urban air-pollution episodes. Duststorms, however, tend to be of shorter duration than urban air-pollution episodes; whole days of blowing dust at a station were rare. To estimate average duststorm duration, we divided total hours of dust by the number of dusty days and obtained 6.6 h.

Attempts to correlate visibility during duststorms with various powers of windspeed failed. Even at individual stations during duststorms of several hours' duration, windspeed and visibility could not be correlated.

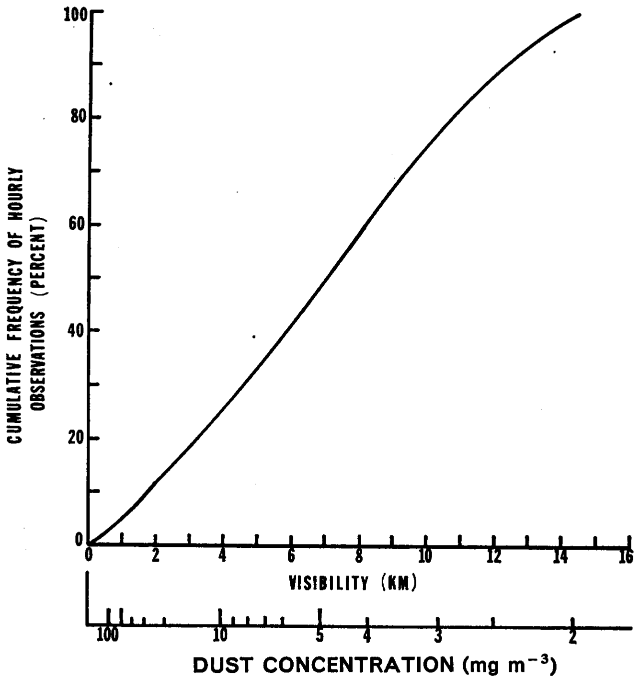

FIG. 5. Cumulative frequency distribution for more than 30,000 hourly visibility observations and computed dust concentrations during dusty hours in the 1950's at 37 Great Plains stations.

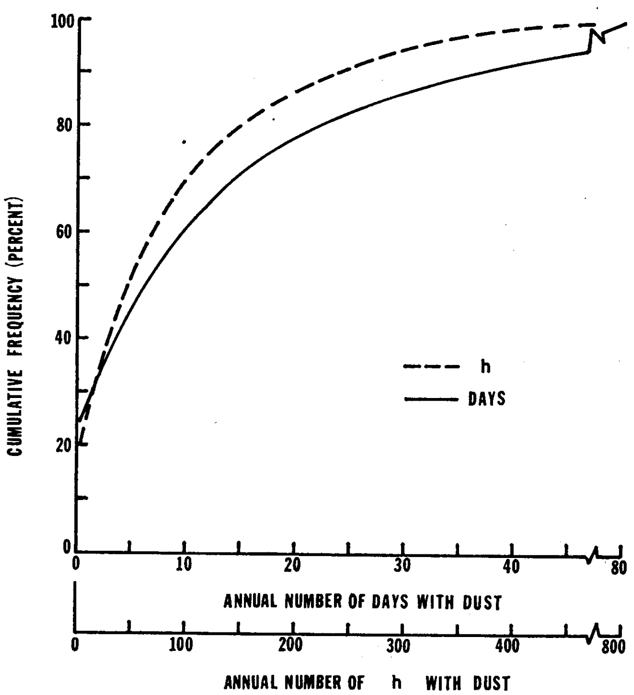

FIG. 6. Cumulative frequencies of annual number of hours and days of dust at 37 Great Plains stations during 1950's (370 observations for each curve).

TABLE 2. DUSTY DAYS, DUST CONCENTRATIONS AND VISIBILITIES SUMMARIZED

Station name	Dust	Average concentration*	Average visibility*
	(No. days y^{-1})	(mg m^{-3})	(km)
El Paso, Tex.	42.5	14.8	7.1
Amarillo, Tex.	34.4	13.4	8.0
Laredo, Tex.	14.6	10.2	7.7
San Antonio, Tex.	8.4	8.1	7.4
Corpus Christi, Tex.	7.6	6.6	8.5
Waco, Tex.	10.5	9.7	8.0
Dallas, Tex.	8.0	11.0	7.1
Abilene, Tex.	19.4	10.3	7.4
Wichita Falls, Tex.	18.3	10.8	7.7
Midland, Tex.	31.4	13.1	6.9
San Angelo, Tex.	22.4	9.1	6.4
Lubbock, Tex.	47.5	11.7	7.9
Roswell, New Mex.	22.1	15.8	6.9
Albuquerque, N. Mex.	24.3	16.4	6.1
Oklahoma City, Okla.	11.2	9.5	8.5
Tulsa, Okla.	7.8	5.4	8.8
Goodland, Kan.	34.7	32.2	6.6
Dodge City, Kan.	23.6	14.6	7.4
Topeka, Kan.	4.0	6.0	8.7
Wichita, Kan.	15.0	7.0	8.5
Denver, Colo.	9.1	8.0	7.4
Grand Junction, Colo.	1.3	5.2	8.4
Pueblo, Colo.	10.2	23.1	6.6
North Platte, Nebr.	7.6	9.8	7.6
Grand Island, Nebr.	6.2	6.3	8.2
Norfolk, Nebr.	5.7	5.1	8.8
Cheyenne, Wyo.	1.7	12.0	5.8
Sheridan, Wyo.	0.1	49.2	3.2
Casper, Wyo.	0.7	7.5	6.8
Rapid City, S. Dak.		No dusty days	
Sioux Falls, S. Dak.	2.7	4.8	9.2
Huron, S. Dak.	4.2	4.9	9.2
Bismarck, N. Dak.	3.5	5.4	8.8
Williston, N. Dak.	4.2	9.7	7.9
Fargo, N. Dak.	8.2	9.7	7.7
Billings, Mont.	0.1	5.0	8.8
Glasgow, Mont.		No dusty days	

* Based on hourly observations during dusty days when (a) visibility was less than 11.3 km (7 miles) and dust was reported and (b) visibility was 11.3–14.5 km (7–9 miles) and the windspeed exceeded 5.4 m s^{-1} (12 miles h^{-1}).

The average annual number of days with dust reported at each station ranged from none to 47.5 (TABLE 2). The median number of dusty days annually was 7; 20 per cent of the reports of the Great Plains stations indicated 22 or more dusty days annually during the 1950's (FIG. 6). On an hourly basis, the median annual number of dusty hours was 45. About 18 per cent of the reports for the 1950's indicated no hours with dust, though 20 per cent indicated more than 150 h of dust per year. Thus, about equal numbers of annual reports indicated no air pollution as indicated significant air pollution from duststorms.

The number of dusty hours also varies with location in the Great Plains. During the 1950's the annual average number exceeded 150 in the driest area of the Southern Great Plains but decreased away from that area (FIG. 7). Although average number of

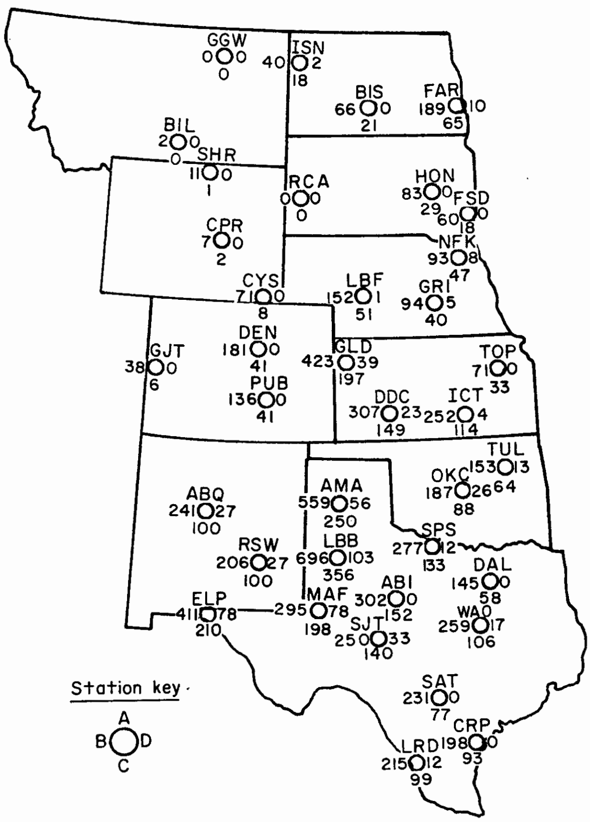

FIG. 7. Plot of stations showing station abbreviation (A), maximum annual number of dusty hours (B), average annual number of dusty hours (C), and minimum annual number of dusty hours (D) at 37 Great Plains stations during 1950's.

dusty hours depends mostly on local erosiveness, there appears to be reasonable continuity between adjacent stations. Because of large variations in precipitation during the 1950's, the maximum and minimum annual dusty hours probably represent limits that can be expected under present agricultural practices. During years with above-normal precipitation many stations reported no dusty hours, though four stations had more than 50 h of dust per year during such periods. When precipitation was below-normal, maximums of 200–700 h of dust annually were reported at many

Southern Great Plains stations and most Great Plains stations had a significant number of hours with dust.

SUMMARY AND CONCLUSIONS

Because humidities are low and particle-size distributions are relatively constant in duststorms, it appears feasible to estimate particulate concentrations from visibility measurements made during duststorms. Compared with urban air pollution episodes, duststorms have shorter durations but larger particles and higher particulate concentrations. For duststorms in the Great Plains in the 1950's, the median dust concentration was 4.85 mg m^{-3}, and the average duration was 6.6 h. Because of such high concentrations of coarse particles during duststorms, air-pollution laws for Great Plains states probably should specify particle-size distributions (to which various sections of the laws apply) as well as limits on particulate concentrations.

Depending upon precipitation, annual hours with dust at Great Plains stations ranged widely, but both number of hours with dust and average dust concentration during duststorms were highest in the driest area of the Southern Great Plains. During the 1950's the median annual number of hours with dust was 45, but more than 150 dusty hours were reported in 20 per cent of the observations. When annual precipitation is low, most Great Plains locations have a significant number of hours of dust.

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